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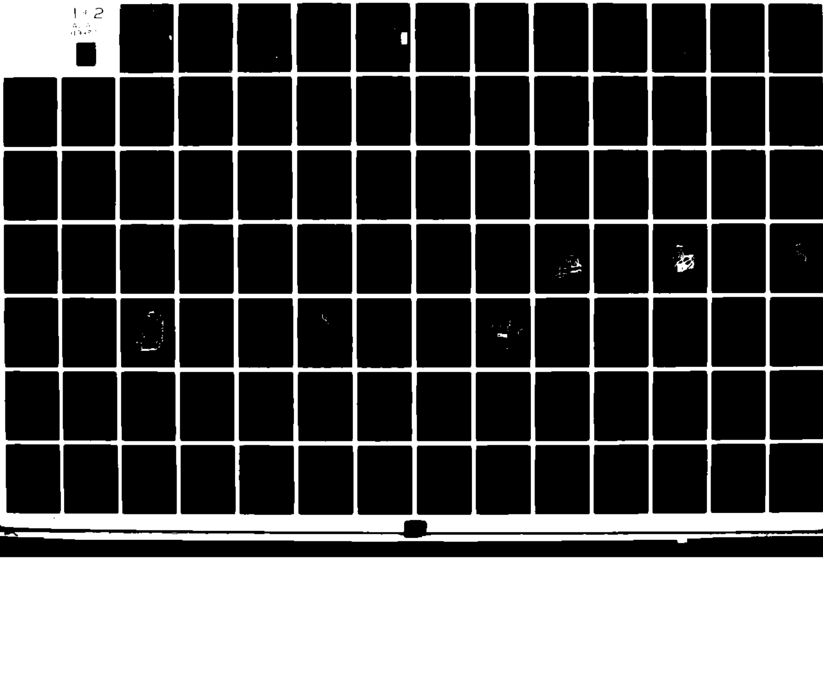

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DUST EVALUATION

IN THE COTTONSEED OIL INDUSTRY

By: Jerry F. Thomas

Major Professor: Charles H. Lawrence, Ph.D.

Occupational exposure to cotton dust (heterogenous mixture) is a potential hazard for approximately 560,000 workers employed throughout the U.S. cotton industry, where 84,000 are estimated to have the disease byssinosis, (caused by unknown component of cotton dust).

In addition to reducing the existing exposure limit in the textile fraction of the industry, the final cotton dust standard of 1978 established permissible exposure limits for other components of the industry, including cottonseed oil mills where approximately 4,000 workers are employed. The permissible exposure limit for cotton dust in cottonseed oil mills was specified at 500 $\mu g/m^3$ of lint-free respirable cotton dust averaged over an 8-hour work shift, as collected by a Lumsden-Lynch vertical elutriator which is intended to collect particles that are 15 µm or less in diameter. This standard was stayed from implementation by a U.S. Court of Appeals.

This investigation was designed to evaluate the dust conditions in the cleaning, delintering, hulling and separating, and baling processes of a cottonseed oil mill and to evaluate the performance and applicability of the Lumsden-Lynch vertical elutriator by utilizing Bendix and MSA personal samplers to collect side-by-side samples with the elutriator for gravimetirc as well as microscopic analysis. Additionally, the variability of the heterogeneous cotton dust from process to process and season to season was evaluated. The study was accomplished at a mill employing approximately 80 workers in a 24-hour per day, 7-day per week schedule that was capable of processing 500 tons of seeds per day.

Analyses of the samples revealed that dust concentrations exceeded the permissible exposure limits in every process evaluated, and was true for both summer and winter samples; however, lesser concentrations were observed during the winter when "green" seeds and high relative humidity prevailed. Microscopic analyses demonstrated that 34 out of 34 samples collected by the Lumsden-Lynch vertical elutriator during the summer had particles larger than 15 µm in diameter, with 32 out of the 34 having some particles larger than 21 µm in diameter. The personal samplers demonstrated very similar particle sizes and when compared to their vertical elutriator counterparts, according to largest inclusive particles for the 99.9 per cent cumulative, no statistically significant difference was evident between the samplers. So, the vertical elutriator did not perform as intended in this industry. Carbohydrate and protein analyses

A

indicated a wide variability in the heterogeneous mixture of cotton dust from process to process and season to season; thereby, contraindicating a single gravimetric standard applicable throughout the cottonseed oil mill. Overall, the most salient observation was the need for identifying the etiological agent(s) so an appropriate standard can be determined.

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Lieutenant Colonel

UNITED STATES AIR FORCE

1981

DUST EVALUATION IN THE COTTONSEED

OIL INDUSTRY

121 Pages

DOCTOR OF PHILOSOPHY

UNIVERSITY OF OKLAHOMA

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DUST EVALUATION IN THE COTTONSEED OIL INDUSTRY

A DISSERTATION

SUBMITTED TO THE GRADUATE FACULTY

in partial fulfillment of the requirements for the

degree of

DOCTOR OF PHILOSOPHY

BY

JERRY FRANKLIN THOMAS

Oklahoma City, Oklahoma

1981

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DUST EVALUATION IN THE COTTONSEED

OIL INDUSTRY

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DUST EVALUATION IN THE COTTONSEED OIL INDUSTRY

CHAPTER I

INTRODUCTION

For some time dusts of cotton, flax, and soft-hemp have been known to cause a lung disease referred to today as byssinosis (1). The disease was first described in the early 1700s by Ramazzini (2) who recognized that flax and hemp dust caused what he described as an asthma-like disease, which later became known as byssinosis and was associated with cotton dust in the 1800s (1). Following Whitney's invention of the cotton gin in 1793, and the resulting increase in cotton production and processing (140,000 pounds in 1791 to 35 million pounds in 1800), the number of workers being exposed to cotton dust increased dramatically (1,3).

Prior to and following the Civil War, much of the cotton produced in the U.S. was shipped to Great Britain for processing into yarn and cloth (4). Because of this, one of the first reports of textile mill pollution with cotton dust concerned British mills and as early as 1820, Lancashire physicians reported an excess of respiratory disease among cotton mill workers (1). The acute symptoms of byssinosis, dyspnea and shortness of breath on Mondays after a weekend away from the mills, were first described by two Belgian physicians, Mareska and Heyman (1). In 1845, they interviewed 1000 men and 1000 women in the mills of Ghent, and all workers declared that the dust bothered them much less on the last days of the week than on Monday.

An abundance of literature on the medical problem associated with cotton dust and the textile industry has been generated since those early studies (1). The British Government officially recognized byssinosis as an occupational disease in 1932 (5), and then in 1941, made it a compensable disease (6). In contrast, the U.S. Public Health Service concluded in 1932, that dust concentrations in American cotton mills were too low to cause health problems. Because of a lack of adequate documentation and evaluation, byssinosis was not recognized as a problem in the U.S. until the 1960s (5).

Following recognition of the cotton dust problem in U.S. cotton textile mills, another 8 years (1968) passed (5,7) before a cotton dust exposure limit was established. This first limit was 1000 $\mu g/m^3$ "raw cotton dust" and became a Federal standard in 1970; however, this standard covered only the textile fraction of the cotton industry. Based upon further studies, the National Institute for Occupational Safety and Health (NIOSH) (7) recommended, in 1974, that the standard be lowered to the lowest feasible limit. The Occupational Safety and Health Administration (OSHA) followed the NIOSH recommendation which resulted in the final cotton dust standard being promulgated in June, 1978 (7).

The final standard lowered the permissible cotton dust exposure limit to 200 $\mu g/m^3$ for the textile industry, but changed from "raw cotton dust" to lint-free respirable cotton dust averaged over an 8-hour work shift. For the first time, an exposure limit for cotton dust was also established for the non-textile industries involved with processing cotton and cotton products. The standard for these industries was a single 500 $\mu g/m^3$ permissible exposure limit. Prior to 1978, the non-textile portion of the cotton industry was subject to a different type and much more lenient standard, nuisance dust at 10 mg/m^3 or 10,000 $\mu g/m^3$ (8,9). Attempts to apply the standards have revealed several problems including the philosophy of setting exposure limits when the etiologic agent is unknown (10,11), especially when the standard is based on the gravimetric analysis of a heterogeneous dust sample which varies in composition from industry to industry and process to process.

In addition to the permissible levels established by the new standard, the sampling procedure was also prescribed. The protocol specified the Lumsden-Lynch vertical elutriator (7) as the sampling instrument, which, when operated according to instructions, is intended to collect dust particles less than or equal to a 15 μm aerodynamic equivalent diameter (7,12). Because it appears to have some irregular flow patterns resulting in particles larger than 15 μm being collected, the reliability of the instrument has since been questioned (12). Application of the sampling instrument to all segments of the cotton industry could, therefore, result in misapplication of the standards. Because of these and other unanswered questions concerning the standard and its application in the cotton industry, it was challenged and a U.S. Court of Appeals ordered a stay on its implementation (10).

It has been estimated that 560,000 workers are employed throughout the cotton industry and approximately 84,000 of these have byssinosis in varying stages (10). At least 35,000 workers in just the textile sector of the industry have become permanently disabled due to this disease (10). It has also been estimated that the incidence of byssinosis may be as high as 21 per cent among the 4,000 employees of the cottonseed oil sub-industry (10). This is attributable, at least in part, to the estimated 8,000 pounds of dust handled per day in the pneumatic and mechanical conveying equipment of a single cottonseed oil mill (7).

Obviously much work has been done in the industry as a whole, but much additional work is needed, especially in the cottonseed oil segment of the industry (12-18).

CHAPTER II

LITERATURE REVIEW

Development of the Cottonseed Oil Process

Cotton is a vegetable fiber, distinguished by its spiral twist, a character that renders it especially valuable for spinning. The cotton plant belongs to the genus *Gossypium*, a member of the *Malvaceae* family of plants (4), which have been found widely distributed throughout the world. Because of the cotton plant's adaptability to a great variety of soils and climates, its fiber has probably been used by more people and for more purposes than any other natural fiber (4). The three kinds of cotton considered to be most important for commercial value are Sea-Island, Egyptian, and Upland (3,4), each of which has a different type of fiber (3). Many variations and hybrids from the Sea-Island and Upland cottons, found in the U.S., have been developed over the years (4).

The first country to use cotton is not definitely known; however, records indicate that as early as 3000 B.C., people in India grew cotton and spun the fibers (4). The excellence of the cotton fiber was known to the Greeks and Romans, and ancient Peruvian tombs have yielded mummy cloths of cotton (4). Alexander the Great introduced cotton to Europe in the 4th century B.C.; it was called "the vegetable lamb of Tartary." For many years after cotton became common in Europe it was known as "cotton wool" (4).

For hundreds of years after the cotton textile fiber was introduced into Europe, cotton clothing was unaffordable for all but the more wealthy (3). One of the reasons for cotton material being so expensive was that during this period the seed had to be separated from the fiber by hand. An entire day was required for a man to remove the seed from 1 pound of cotton (3).

Cotton was one of the treasures that Columbus hoped to find when he sailed from Europe in search of a westward route to India (3), and he did in fact, find cotton growing in the New World when he discovered the West Indies in 1492 (3). This cotton was the Sea-Island type and is considered indigenous to America (3,4). The first Sea-Island cotton exported from the U.S. was grown in Georgia, by Bisset in 1788 (19). The Upland cottons are also found in America, but they differ from the Sea-Island types in several ways (3,4,19,20).

a) Upland varieties are grown over a much wider and more varied territory, so, the total production far exceeds that of the Sea-Island types.

b) Sea-Island types produce a longer-staple, more valuable fiber than the Upland types.

A slender thread of 100 miles or longer can be made from 1 pound of Sea-Island cotton.

c) The seeds of the Upland types are large, surrounded by dense fuzz, and are more difficult to separate from the fiber than the smaller black seed of the Sea-Island types.

At one time, the best known fiber in the U.S. came from Sea-Island cotton; however, very little of it is currently grown. Problems encountered with trying to produce large quantities of this type have been heavy damage from the boll weevil, and areas where it will grow well being limited to the islands along the coast of Georgia and South Carolina (3).

Though the value and usefulness of the cotton fiber have been recognized in many countries for centuries, the cottonseeds, except for the small quantity utilized for seed and livestock feed, have been considered a waste product and a nuisance (4,20). In 1783, the London Society for the Encouragement of Arts, Manufactures, and Commerce directed attention to the fact that cottonseeds contained an oil that might be made useful (4,20); however, the society did not know the real value of the oil or a method for its extraction (4).

The first recorded attempt to crush cottonseeds and extract oil in the U.S. was at Natchez, Mississippi, in 1834

(4,20). The project was considered a failure and was abandoned after heavy financial losses. Thirteen years later, in 1847, two men from New Orleans tried to solve the problems in extracting the cottonseed oil but also met with failure (20). One of the would-be problem solvers exhibited a small bottle of crude cottonseed oil, which he stated had cost him $12,000 in their attempt (4,20).

During this period, the extraction of oil from cottonseed was advancing much more rapidly in France, than in the U.S. (20). In 1852, Aldige visited France, and became familiar with the cottonseed oil extracting procedures that had been developed there. The next recorded attempts to extract cottonseed oil were by two groups in New Orleans, in 1855. One of the groups included Aldige (20). At the same time, Union Oil Company located a cottonseed oil mill in Providence, Rhode Island, and depended on the South to supply the seeds (20). This mill closed during the American Civil War when their seed supply was terminated (20).

Prior to 1860, most of the cottonseeds generated presented a disposal problem for the ginner and created concern in the local community. The seeds were usually hauled to a remote place to rot, or were dumped into a convenient stream of running water. The seed disposal problem became so serious that the Mississippi legislature passed laws requiring gins to remove or destroy all cottonseeds generated by the gin if it were located within half a mile of any city, town or village, so the health of the people would not be "prejudiced" (20). Another Mississippi law prohibited cotton gins from dumping cottonseeds into any river, creek, or other stream of water which might be used for drinking or fishing. These laws provided specified fines for violators (20).

With the American Civil War, little progress was made in the cottonseed oil industry in the U.S. from 1861 until a few years after the war. It was during this time though that the South first used the seed-cake and hulls (by-products of oil extraction) for feeding cattle (4). The valuable properties of the seed-cake for animal food had been known for some time in Europe, but never used to any extent in the U.S. before the war. With a few small mills and refineries at Vicksburg and New Orleans and the blockade of the Mississippi, feeding of the seed-cake to cattle developed for a lack of anything better to feed (4).

By 1860, a total of seven mills for extracting oil from cottonseed existed in the U.S. The economic problems with reconstruction in the South, after the Civil War, resulted in there being only four cottonseed oil mills left by 1867 (20), but by 1870, the number had increased to 26 (4). The number of mills continued to increase so that by 1900, a product that had been considered a nuisance provided materials valued at $42,411,835, and only slightly over half of the available raw material was used (20).

Not only did the number of cottonseed oil mills increase rapidly after 1870, but so did the number of new uses for the oil. By 1902, a mail survey of the cottonseed oil industry revealed that a total of 618 mills were in existence in the U.S. (20). Eventually, the number of mills started to decrease, but the volume of seeds handled by each increased (18). In 1963, the number of active mills had declined to 188, and by 1977, only 83 active mills remained (18); however, the total dollar value of cottonseed oil mill products continued to increase. The value of the cottonseed oil industry products was $458 million in 1972, and $650 million in 1976 (18).

The value of the cottonseed oil industry products not only has increased over the years because of the ever increasing number of marketable products and discoveries of new uses of the products, but also because of volume and inflation. At one of the Oklahoma mills each ton of cottonseeds produces an average of 320 pounds of oil, 160 pounds of linters, 550 pounds of hulls, and 920 pounds of cottonseed meal and cake (21). Approximately 50 pounds of each ton of seeds are lost during processing. Some of the major product uses are (21):

a) cottonseed oil which is used in food products including cooking oil, mayonnaise, salad dressing, margarine, packing oils, and shortening,

b) linters, some of which are used for padding in mattresses, and automotive and furniture upholstery, while others are converted to different forms of cellulose and used in the manufacture of film, cellophane, plastic products, and explosives,

c) hulls, some of which are used for livestock feed, mulch, soil conditioner, and oil well drilling mud additive, while some are used to produce materials for synthetic rubber and petroleum refining, and

d) cottonseed meal and cake, which are used mostly for feeding livestock, with some being used in fertilizer.

The general processing of cottonseeds through a cottonseed oil mill starts with the seeds being hauled from surrounding and/or outside areas and placed in storage. Seeds are removed from storage and cleaned to remove materials such as bolls, sticks, rocks, and pieces of metal that might cause problems in subsequent operations (8). Next comes delintering to remove lint remaining after ginning (20), followed by hulling and separation of the hulls from the meats. The lint is pressed into bales and the hulls are transferred to storage. The seed meats are prepared for oil extraction by steam cooking, followed by flaking. Oil is extracted from the seed-meat flakes with hexane. The oil and hexane are separated and the flakes are dried and made into meal or cake (21). Many of these process areas cause cotton dust (a heterogeneous mixture of materials associated with growing and processing cotton) to be released into the breathing zone of the workers; thereby, posing a potential health hazard.

Byssinosis

Cotton dust is defined in the final mandatory OSHA standard of 1978, as dust present in the air during the handling or processing of cotton (7). The dust may contain a mixture of many substances including cotton plant fragments, fiber, bacteria, fungi, soil, pesticides, non-cotton plant matter, and other contaminants which may have accumulated with the cotton during growing, harvesting, processing or storage. All dust present during the handling and processing of cotton through the weaving or knitting of fabrics, and dust present in other operations or manufacturing processes using new or waste cotton fibers or cotton fiber by-products from textile mills is considered cotton dust (7).

The disease currently described as byssinosis actually occurs in workers exposed to dusts from cotton, flax, or soft hemp (22-25). Ramazzini (2) first described the breathing problems of flax and hemp workers in the early 1700s. He described the dust generated during the carding of hemp and flax as "foul and poisonous; which, upon entering the mouth, then the throat and lungs, makes the workmen cough incessantly, eventually bringing on asthmatic troubles." His description of the hemp worker's dust problem is as follows.

> They work mostly in confined rooms because of the severe cold of winter which is their regular season for this work, hence while they comb the hemp which has been well smeared with grease they cannot help taking in foul particles by the mouth; these pollute the spirits and stuff up the organs of respiration; hence arise serious ailments (2).

As previously described, the acute symptoms for byssinosis among workers exposed to cotton dust were first described in 1845, by Mareska and Heyman (1), who interviewed 1,000 men and 1,000 women in the mills of Ghent. The symptoms were dyspnea and shortness of breath on Mondays after a weekend away from the mill. The workers stated that the dust troubled them much less on the last days of the week than on Monday and Tuesday (1). The supervisory personnel blamed the effects on what was described as "excesses of the Sunday"; however, the workers attributed the effects to the "interruption of work which makes them lose part of their habituation to dust" (1). In spite of the early recognition of human health problems associated with cotton dust, the problem of byssinosis has persisted in the cotton industry (1,7,10).

Byssinosis is described presently as a chronic respiratory disease that can be found in some workers after years of exposure to cotton dust, and is characterized by difficulty in breathing or tightness of the chest on the first day after return to work following an absence (10,26,27). There are four grades of byssinosis. Using a subjective symptoms test, Shilling established a grading system as follows (7,28):

a) Grade 1/2: occasional chest tightness and/or cough on first day of the working week,

b) Grade 1: chest tightness on every first day of the working week,

c) Grade 2: chest tightness on first and other days of the working week, and

d) Grade 3: Grade 2 symptoms accompanied by evidence of permanent disability from reduced ventilatory capacity.

The lower grades of byssinosis are usually reversible; however, Grade 3 subjects will have some permanent impairment of the ventilatory capacity (10,28). Among cotton textile workers the disease is commonly known as "brown lung" (29).

Research and reports on cotton dust and health problems have been abundant from other parts of the world during the interim since recognition of the health hazard (1,7,10,24,30, 31); however, only in the past 20 to 30 years has much research on byssinosis been performed in the U.S. The actual seriousness of the problem in the U.S. was not brought into focus until the late 1960s, when Bouhuys et al. (32,33) demonstrated that byssinosis not only existed in the U.S. but was probably widespread. In one of the studies, his group evaluated conditions and prevalence of byssinosis at the Federal Penitentiary in Atlanta, Georgia, where a high incidence of the disease among the workers was found (5,32). Since the Bouhuys' investigations, numerous studies of U.S. workers have been completed. One of the largest of which included 10,133 textile workers at 19 Burlington Industries plants (34). This study revealed an average prevalence of 5.2 per cent of the workers in all areas where cotton was used as the raw material, had byssinosis. Some work areas demonstrated a prevalence as high as 26.2 per cent.

To emphasize the debilitating effects of byssinosis, Fishel (29) described a cotton textile worker of 40 years, employed in Roanoke Rapids, North Carolina. In the earlier years of her employment the worker walked a block and a half to work; unfortunately, during the years, she developed byssinosis with ventilatory impairment to such a degree that she had to be driven the short distance to work. Byssinosis or "brown lung" has been the leading industrial disease affecting women (29); however, it was not officially recognized as an occupational disease in this country until 1968, and the first compensation award for the disease was not made until 1971 (35). This compares with Great Britain's recognition of byssinosis as an occupational disease in 1932, and making it a compensable disease in 1941.

Possible Etiological Agents

In addition to knowing that some agent or agents in cotton dust may cause byssinosis, a number of investigators have reported that byssinosis and chronic bronchitis are both influenced by cigarette smoking combined with exposure to cotton dust (34,36-39). Also, the fact that significant variations in the "trash" composition of raw cotton have been demonstrated (40), further complicates trying to identify a specific etiological agent for byssinosis. Where cotton is grown, how it is processed, and whether the workers smoke or not, all play influential roles on the health of the cotton industry employee. A very significant problem has been and continues to be the identity of the exact etiological agent or agents responsible for byssinosis (11,41,42).

Studies to determine the physiological responses of humans subjected to cotton dust over time were conducted at Duke University Medical Center in the Division of Environmental Medicine (43). One investigation was accomplished by evaluating two groups, one group exposed on the job for 5 days each week to a dusty atmosphere of particles $\leq 10\ \mu$ diameter at 1.0 mg/m^3 and one exposed in a controlled chamber. These studies resulted in the following physiological response observations.

a) A significant decrease in forced expiratory volume in 1 second (FEV_1) was observed in the asymptomatic workers as well as those with byssinosis during exposure to cotton dust.

b) Oxygen tension decreased in arterial blood during exposure.

c) Polymorphonuclear (PMN) leukocyte counts in the peripheral blood increased during cotton dust exposure.

d) The PMN leukocyte to epithelial cell ratio from nasal smears increased during cotton dust exposure.

Kilburn (44) also demonstrated recruitment of PMN leukocytes in mammalian lungs, when exposed to dusts generated from cotton dust extracts. The extracts used contained quercetin, a polyphenol plant flavone present in leaves and bracts of cotton. The extract was dispersed at concentrations of 60 to 110 mg/m^3 in chambers where a group of hamsters were exposed 4 hours per day, 5 days per week for 2 weeks and 1 day. The hamsters were sacrificed after the 11th exposure and the tissue sections prepared from these animals revealed PMN leukocyte recruitment on airways from trachea to terminal bronchioles.

Nicholls and Skidmore (45) used isolated guinea-pig ileum in a bioassay technique to compare the smooth muscle contractor activity of various dusts from mills in which the prevalence of byssinosis was known. Samples of airborne dust were collected in the cardrooms of two Lancashire cotton mills, where one mill was using fine cotton and the other coarse. A previous study had demonstrated the prevalence of byssinosis among the workers of the cardroom processing fine cotton to be 22 percent while the prevalence of the disease among the workers of the cardroom processing coarse cotton was 63 percent. Extracts of the dust collected in the cardroom processing coarse cotton proved to possess a greater amount of smooth muscle contractor activity than extracts of the dust from the cardroom processing fine cotton. The assumption was made that the substance contracting the ileum is responsible for the contraction of animal and human bronchial muscle seen in vitro with cotton dust extracts.

A 3-year study to evaluate acute and chronic changes in the ventilatory capacity of workers was completed in 14 cotton and two man-made fibre spinning mills in Lancashire (46). The study population included 1857 men and women between the ages of 15 and 65. Of the 14 mills processing cotton, eight were processing coarse cotton and six were processing what was referred to as medium cotton. The FEV_1 was evaluated to determine annual decline as well as decline on Monday, during work. In evaluating chronic changes, those without byssinosis had mean annual declines similar to those with byssinosis. Among the workers without byssinotic symptoms, those working in cotton mills had a higher mean Monday fall in FEV_1 than those working in man-made fiber mills. For the workers with symptoms of byssinosis an increased Monday fall was demonstrated only in those working with coarse cotton.

Hitchcock (47) used human autopsy lung and extracts from cotton plant parts to induce histamine release in vitro as a model for the acute response to cotton dust. Human lung was obtained within 6 to 16 hours post mortem from patients whose primary cause of death was not lung disease. The lung was prepared and exposed to extracts of various cotton plant parts under controlled laboratory conditions. Only components of cotton bracts (leaf growing under cotton boll) extracts caused the release of detectable amounts of histamine from the chopped human lung. Hitchcock concluded that the histamine release from the chopped autopsy lung could serve as a useful model system to study *in vitro* the nature of the acute response to cotton dust. *In vivo* observations were correlated with the *in vitro* studies to suggest that cotton dust does indeed contain a pharmacological agent capable of releasing histamine.

Evans and Nicholls (48) performed a similar *in vitro* histamine release study in which extracts were made from total cotton dust collected from the cardroom of a Lancashire cotton mill processing coarse-grade cotton. The lung specimens used in this study were from 6-month old pigs of both sexes or from human lung taken from 42-to 49-year old male patients during surgical lung resections at a local hospital. The results confirmed that cotton dust contains a water-soluble fraction that releases histamine from human and pig lungs *in vitro*. Since total cotton dust was used, nothing could be said about the effects of any particular cotton plant part or adherent.

In one of the studies by Hitchcock *et al*. (49), specific cotton plant parts were evaluated as possible causative agents for byssinosis. Their approach was to take extracts from a specific plant part, after processing, and incubate it with prepared human, guinea-pig and rat lung.

Only extracts of the bracts possessed any significant histamine releasing agent, and then only from the human lung. All extracts failed to cause detectable histamine release when incubated with guinea-pig or rat lung.

Kosmidou-Dimitropoulou et al. (50) provided additional support for bract being a potential causative agent. As previously mentioned, identity of the bioactive agent responsible for byssinosis is uncertain, but some of the suggested chemical substances that may be responsible such as quercetin (a polyphenol plant flavone) are found in the bracts and leaves of cotton (44,50). The investigators quantitiated the number of capitate hairs (hairs composed of a unicellular or multicellular head on a narrow stalk) remaining attached to bract and leaf fragments in raw cotton lint used by yarn manufacturers. The capitate hairs are known to contain phenolic and terpernoid substances, potential sources of chemicals that may cause byssinosis. They found that an average bale of raw cotton lint will contain between 1.23 and 2.54×10^8 capitate hairs of just bract origin alone.

If bracts do contain the causative agent for byssinosis, then a study by Morey and Wakelyn (51) would indicate that process materials from cottonseed oil mills are less hazardous to work with than those from a cotton textile mill. They identified about 9 per cent of the "trash" materials in willowed picker (cleaned and blended lint and "trash" materials remaining after processing raw cotton through a picker machine at the textile mill) as bract. The bract content identified in linter "trash" was less than 1 per cent. Linters are fibers remaining on the seed after ginning, and are removed at the cottonseed oil mill. Only minute traces of bract were identified in samples of cottonseed hulls from an oil mill.

In studies completed in cottonseed oil mills, one, which involved 172 workers in four cottonseed oil mills in the southern U.S., revealed high levels of total and respirable dust but low prevalences of byssinosis (52). Even though the researchers found only four workers meeting the symptomatic requirements for byssinosis, the study population did show an acute bronchoconstrictor response on Monday that was not present on Friday of the same week.

Another study of two cottonseed oil extraction plants in Egypt evaluated worker response to associated process dust (53). In this study 30.2 per cent of the workers exposed to high concentrations of cotton dust, composed mostly of plant debris, complained of chest tightness or breathlessness or both. Of 37 workers exposed in grinding and oil extraction, where the dust was composed mostly of seed fragments and parts of the seed, there were no complaints.

Simpson and Barnes (54) examined falls in FEV_1 for workers employed at a cottonseed lint removal and oil crushing plant in New South Wales, Australia and found that workers exposed to high dust concentrations in lint removal sections demonstrated significant falls in FEV_1, with exposure. Workers at the same plant, who were not exposed to cotton dust were not affected.

Proteolytic enzymes, such as those found in cotton dust, have been suggested as another mechanism possibly responsible for byssinosis. Cotton dust was collected in 17 cotton mills (55) and extracts made to determine enzymatic activity, which was then compared with signs and symptoms among the workers in the areas where dust was collected. Dust concentrations were similarly compared with the workers health. Strong correlations between various enzyme concentrations and signs and symptoms were found; however, the correlations observed between dust concentrations were less obvious. Based upon the findings it was suggested that enzymes could be causative agents.

Bacteria have also been suggested as possible causative agents of byssinosis and, at least, two studies in support of this concept have been reported.

a) Cinkotai, Lockwood, and Rylander (56) compared the concentration of airborne microorganisms with the prevalence of byssinotic symptoms among workers in cardrooms or dusty workrooms of seven cotton spinning, two cotton waste, and five willowing mills. They found a strong correlation between the concentrations of gram-negative bacteria and the prevalence of byssinotic symptoms. Endotoxin concentrations in the airborne dusts ranged from 0.0 to 1.6 mg/g dust. There did not seem to be a relationship between the concentration of airborne fungi found and the prevalence of byssinotic symptoms.

b) Rylander and Lundholm (13) identified the predominant bacteria associated with cotton as gram-negative rods of the Enterobacter species. The most frequently isolated gram-negative bacteria in this study of cotton plants, bale cotton, and cotton and cotton wastes from cotton mills, were of the Enterobacter, Pseudomonas, and Agrobacterium species. Aerosols of each of the bacterial species isolated were used to expose guinea pigs to determine leukocyte mobilizing effects. All gram-negative bacteria except Agrobacterium species caused an increase in the number of leukocytes. The number of macrophages also increased with aerosol exposure to all the bacteria except the Agrobacterium species.

Mechanical irritation has also been considered as a possible mechanism that may influence the development of byssinosis (11,57). Respirable dusts were collected in a model cardroom at the USDA Cotton Quality Research Station at

Clemson, South Carolina, while cotton representing different U.S. varieties and growing locations was being processed (57). For each test in this study one bale of cotton, prepared by compositing ten bales of cotton representing a specific variety and growing location, was processed. Six varieties of cotton and five growing locations in the U.S. were evaluated, and the results indicated that growing location affected cardroom dust composition much more than did the variety of cotton. The quantity of inorganic respirable material found was significant and the silica fraction was of potential physiological consequence. The investigators concluded that the possibility of silica and other minerals found in the cotton dust could act as synergists in byssinosis and that more attention should be given to the inorganic fractions of cotton dust.

Cotton Dust Standards

As outlined earlier, the first proposal for limiting the amount of cotton dust a worker could be exposed to in the U.S., came in 1964, and was based upon studies completed in Great Britain by Roach and Shilling. In that year, the American Conference of Governmental Industrial Hygienists (ACGIH) proposed a tentative Threshold Limit Value (TLV) of 1.0 mg/m^3 for raw cotton dust (58). This was adopted by the ACGIH in 1966 (7).

Regulating worker exposure to cotton dust in the U.S. did not come about until 1968 (7), when the Secretary of Labor, under the Walsh-Healy Act, promulgated the 1968 ACGIH list of TLVs which included a raw cotton dust limit of 1 mg/m^3 (1,000 μg/m^3). Initially this exposure limit applied only to Federal employees (5). Subsequently, this limit was adopted as an established Federal Standard under section 6(a) of the Occupational Safety and Health Act of 1970 (7); however, only the workers in the textile portion of the cotton industry were covered.

Further studies indicated the 1,000 μg/m^3 raw cotton dust standard to be much too lenient and in 1972, the ACGIH Threshold Limits Committee proposed changing the TLV to 200 μg/m^3 of lint free cotton dust. Two years later, they adopted the new limit and specified the vertical elutriator as the method of sampling (7). Based upon the ACGIH adopted TLV and various studies indicating the need for changing the standard, the Director of NIOSH submitted to the Secretary of Labor in September, 1974, a recommendation for a new cotton dust standard (7). The recommendation was that any permanent standard should incorporate a program of medical monitoring and management, work practices, and administrative controls, as well as the lowest feasible environmental limit of lint-free cotton dust (58) which, at that time, was indicated at a level of 200 μg/m^3.

OSHA used the recommendation from NIOSH to publish an Advance Notice of Proposed Rulemaking (39FR44769) in December, 1974 (7). The notice requested interested persons to submit their views on specific issues relating to cotton dust or to the NIOSH Criteria Document. This resulted in numerous hearings and proposals that ended with the promulgation of the final standard in June, 1978. The new standard included segments of the cotton industry not previously covered under other cotton dust standards. The permissible exposure limit was set at 200 $\mu g/m^3$ of lint-free respirable cotton dust averaged over an 8-hour work shift for the textile industry except for slashing and weaving, where it was set at 750 $\mu g/m^3$ (7). The sampler suggested in the final standard was the Lumsden-Lynch vertical elutriator.

Other segments of the cotton industry, including the cottonseed oil mills, were assigned an exposure limit of 500 $\mu g/m^3$ of lint-free respirable cotton dust averaged over an 8-hour work shift. Again, the instrument suggested in the standard for monitoring was the Lumsden-Lynch vertical elutriator which, when operated at a flow rate of 7.4 ± 0.2 liters/minute is to collect particles less than or equal to 15 μm (7). Though there is a great deal of information concerning this instrument and its application to monitoring in the textile industry, its performance hasn't been demonstrated in the cottonseed oil industry.

The final standard was challenged, resulting in a U.S. Court of Appeal's order to stay implementation (10). Because of the potential economic impact on the industry if this standard were implemented, Congress directed the Labor

Department to review the final standard and the effects of its enforcement. They were also directed to look for more feasible and inexpensive alternatives as well as review their impact on inflation and the U.S. trade position (10). The stay under the U.S. Court of Appeal's order has since been overruled by the U.S. Supreme Court.

Economic Considerations

The major concern of the various segments of the cotton industry, prior to and since the Court ordered stay, has been the cost of controlling the dust (8,10). Preceding the issuance of the final standard, Parnell et al. (8) studied the cost of lowering dust levels to 200 $\mu g/m^3$ (vertical elutriator collected) in a cottonseed oil mill processing 200 to 225 tons of cottonseed per day. Their study was based upon proposed dust level restrictions which, at the time, were more stringent than the 500 $\mu g/m^3$ actually required by the final standard. The study resulted in estimated costs of $612,125 for required equipment and its installation, and annual costs of controls of $357,826 for the four processing areas of the mill (7,8).

Following issuance of the final standard, the Court ordered stay, and the directive from Congress, the Department of Labor developed estimates of costs for the various segments of the cotton industry to control cotton dust to meet the final standard if implemented (10). The estimates for the cottonseed oil industry were based upon adjustments to the Parnell et al. study to allow for the more lenient exposure limit of 500 μg/m^3 (10). Using 1977 dollars, the estimated total capital costs for all the cottonseed oil industry was \$83.8 million with \$26.2 million annual compliance costs. The overall estimated costs to implement the final standard in all of the industrial segments covered would be \$655.1 million capital costs and \$205.1 million annual compliance costs (10).

The Department of Labor's report to Congress indicated some inflationary impact would result through the industries passing of implementation costs on to product consumers. The overall price increase was estimated to average about 1 per cent of 1977 product prices (10) with increases ranging from about 0.2 per cent in the lowest case (tire cord and fabric) to 2.6 per cent in the highest case (cottonseed oil).

An additional negative aspect of implementing the final cotton dust standard is loss of jobs with an estimated 1,256 jobs lost due to compliance with the standard (10). This would amount to approximately 0.2 per cent of the average 550,300 persons employed in the cotton processing industries in 1977 (10).

If the final standard is implemented, the benefits can be measured in billions of dollars, but more importantly is the improved quality of life, and reduced life stresses which lend to a healthier and more productive member of society.

CHAPTER III

PURPOSE AND SCOPE

It is apparent from the foregoing that the processing of cotton seeds produces high concentrations of airborne dust which represents a heterogeneous and variable mixture of plant fragments, soil, fiber, bacteria, and pesticides, along with other contaminants which may have accumulated during the growing, harvesting, storage, and/or processing of the cotton. It is also apparent that occupational exposure to these dust conditions, which have not yet been fully evaluated, results in a high incidence of byssinosis and that the exact etiologic agent of the disease is unknown. In view of this, the application of a single gravimetric standard to a multi-component dust whose individual constituents vary both qualitatively and quantitatively from process to process, does not afford rational protection or control, especially if the performance of the prescribed monitoring device has raised questions concerning its utilization in industries such as cottonseed processing.

A response to this lack of definitive information stimulated the present investigation and represents its overall purpose. Specifically, this study was designed to:

a) identify and evaluate, using federally specified equipment, procedures, and standards, work areas in a cottonseed oil mill with airborne dust concentrations that exceed the 500 $\mu g/m^3$ standard,

b) utilize alternative sampling techniques and comparative gravimetric and microscopic analyses to evaluate the performance of the Lumsden-Lynch vertical elutriator for sampling airborne respirable dust in the environment of a cottonseed oil mill,

c) develop and apply techniques for estimating the fraction of airborne dust that might be a material other than cotton dust and to evaluate the application of a cotton dust standard to this type of industrial process,

d) recommend, based on an evaluation of the work environment and the application of industrial hygiene principles and concepts, appropriate equipment and procedures for the control of occupational exposure to airborne respirable dust in the cottonseed oil industry.

CHAPTER IV

EQUIPMENT AND PROCEDURES

The cottonseed oil mill utilized in this study employed approximately 80 workers in a 24-hour per day, 7-day per week schedule and was capable of processing 500 tons of seeds per day. Cotton seeds from 57 cooperative gins were delivered to the mill by truck with most shipments occurring in the November to January period, during which time as many as 3,500 tons per day would be unloaded into the 137,000-ton storage capacity. From storage, a conveyance system moved the seeds through the various unit operations depicted in Figure 1.

Cleaning

The purpose of cleaning is to remove materials that might cause nuisance or maintenance problems in the subsequent steps and is, therefore, the first operation to be performed. Materials removed include metallic and wooden debris, bolls, soil, and other foreign objects such as stones. Cleaning is effected by conveying the seeds onto a coarse shaker screen where the large objects are removed and smaller particles, including the seeds, pass through to the next and smaller shaker screen. This process is repeated utilizing increasingly finer screens until the seeds pass from the shaker into a

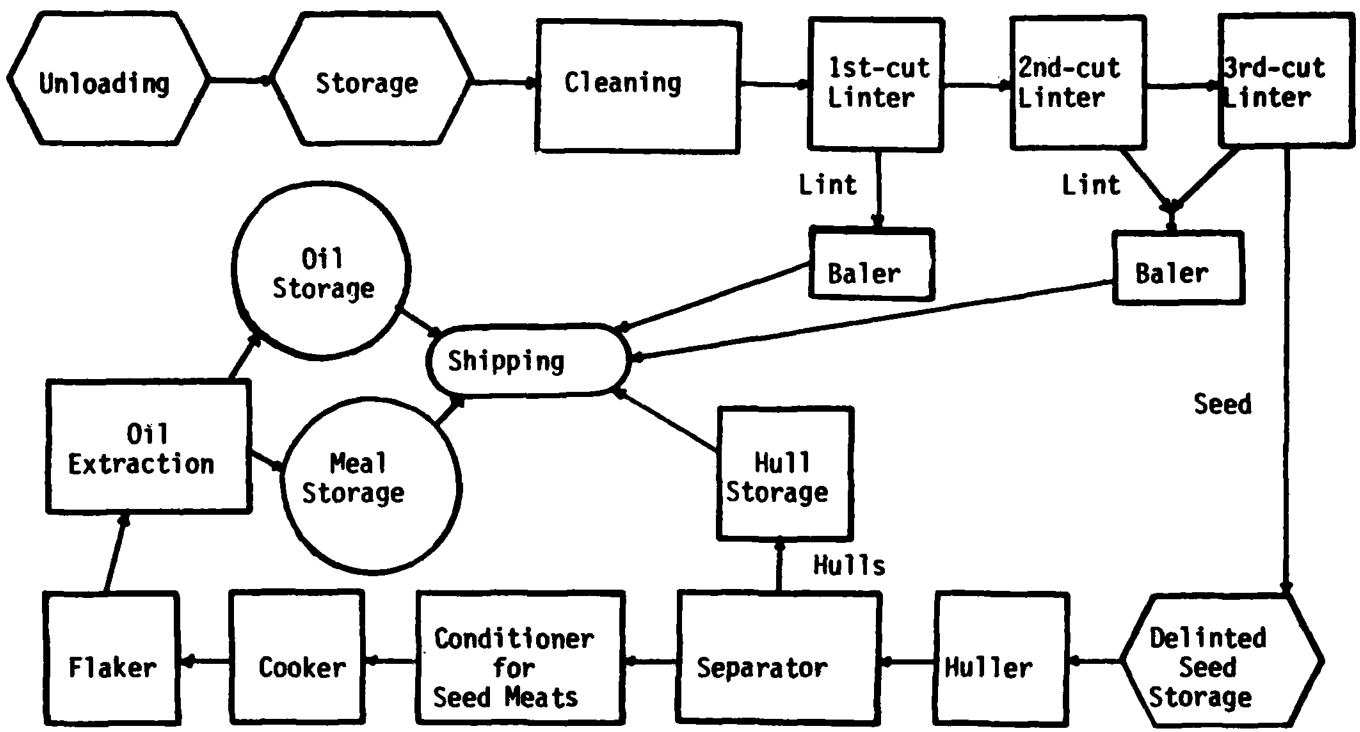

Figure 1. Flow of cottonseed through the cottonseed oil mill.

pneumatic system where the white, "fuzzy" seeds are separated from the black seeds and stones. Sampling as well as visual observation, determined that cleaning was the dustiest process in the mill. Figure 2 is representative of the seed cleaners.

Delintering

From the cleaning operation the seeds are conveyed to the delintering process where the lint adhering to the seed after ginning, is removed by passing the seeds through a

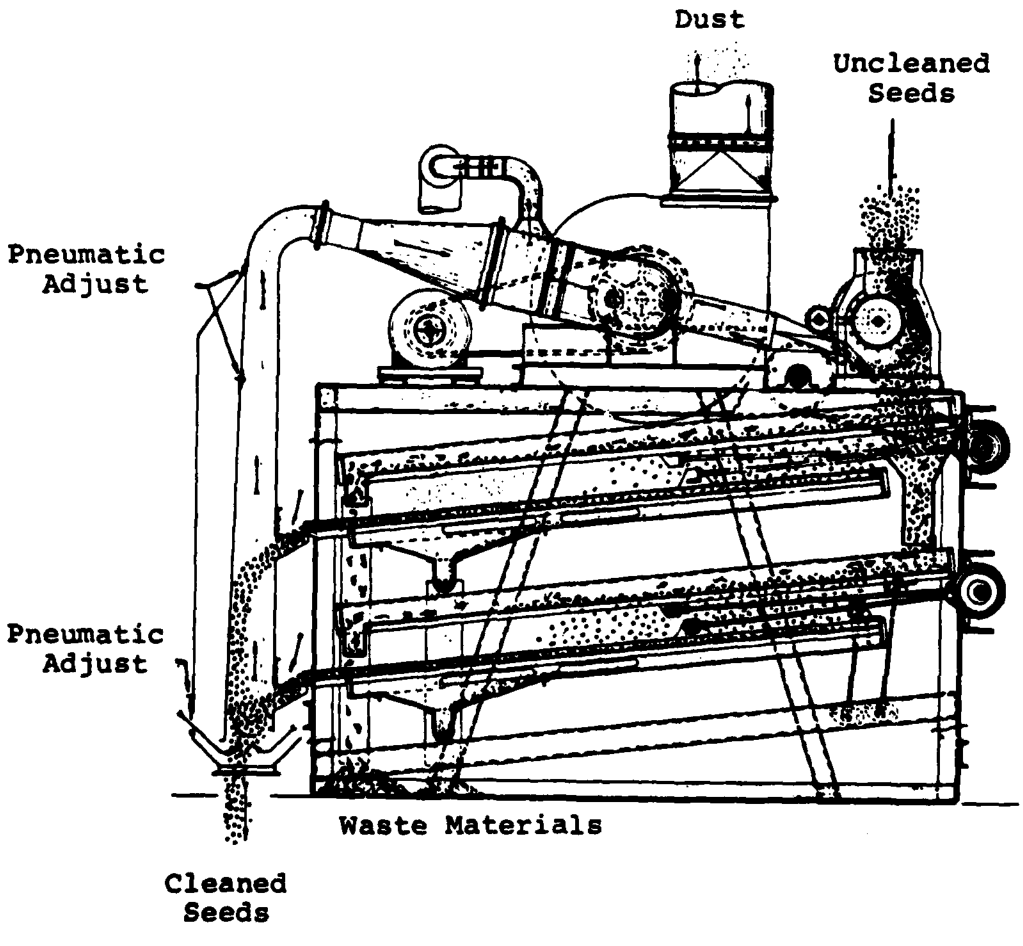

Figure 2. Seed Cleaner.

series of saw blades spaced so that the lint can be removed as the seeds pass between the blades (Figure 3). This process is accomplished in three steps or "cuts." The first cut removes the longer fibers which are ultimately used to produce high quality paper, to mix with wool for felting or fleece, to make surgical cotton, and to stuff mattresses, pads, and cushions. Once removed, the lint is delivered through a system of ducts to the baling room where it is baled separately from the second and third cut linters. The seeds are then moved through the system from the 1st-cut building to another areas of the mill for 2nd and 3rd-cut delintering by the same type of equipment employed in the 1st cut. Linters removed here are delivered to the baling room and baled together for use as a source of high quality cellulose for purposes ranging from photographic film to automobile parts. Though the linters represent very valuable marketable products with many uses, the central purpose for delintering the cottonseeds is to prevent loss of oil through inefficient extraction. The lint remaining on the seeds after ginning must be reduced to 3 per cent or less to prevent excessive loss of oil (59). This removal process also results in the release of large amounts of airborne dust and fibers into the worker's environment.

Baling

As discussed under delintering, the linters from the three cuts go to the baling building where compressed bales weighing in the range of 500 to 600 pounds each are produced.

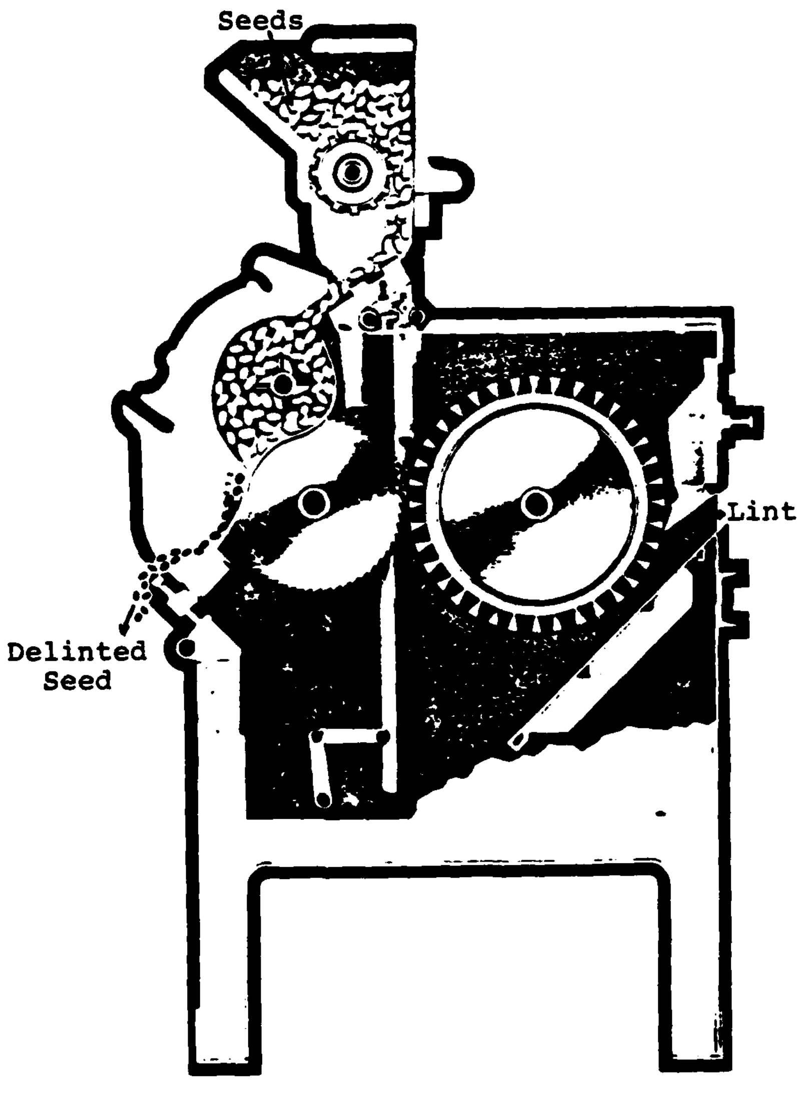

Figure 3. Operation of a linter machine.

Approximately 40 pounds of 1st-cut and 120 pounds of 2nd and 3rd-cut linters are removed from each ton of seeds processed. So, during each 24-hour period thousands of pounds of linters will be removed, transported, and baled in a system that produces an occupational environment heavily burdened with airborne fibers.

Hulling

The delinted seeds arrive in the huller room (from delintering) for decorticating and subsequent separation of the hulls from the seed meats. The seeds first pass through a hulling machine (seed splitter) followed by a series of shakers that separate the cottonseed meats from the hulls (21). From the upper shaker tray, the remaining uncut seeds, hulls, and large seed meats pass to the feeder for the hull and seed separator (60). The uncut seeds, along with some hulls are returned to the huller for decorticating, with the remaining hulls being conveyed to hull "beaters" for further separation of hulls from the fine seed meats, dust, and oily fibers (8). Figure 4 is representative of a typical operating hulling machine and Figure 5 illustrates the operation of a hull and seed separator. Following the hulling and separation process, the hulls are sent to storage as the seed meats start the process that leads to oil extraction. As stated, approximately 550 pounds of hulls are produced from each ton of seed processed. Hulling also produces a dusty worker environment; however, much of the dust produced in this area can be

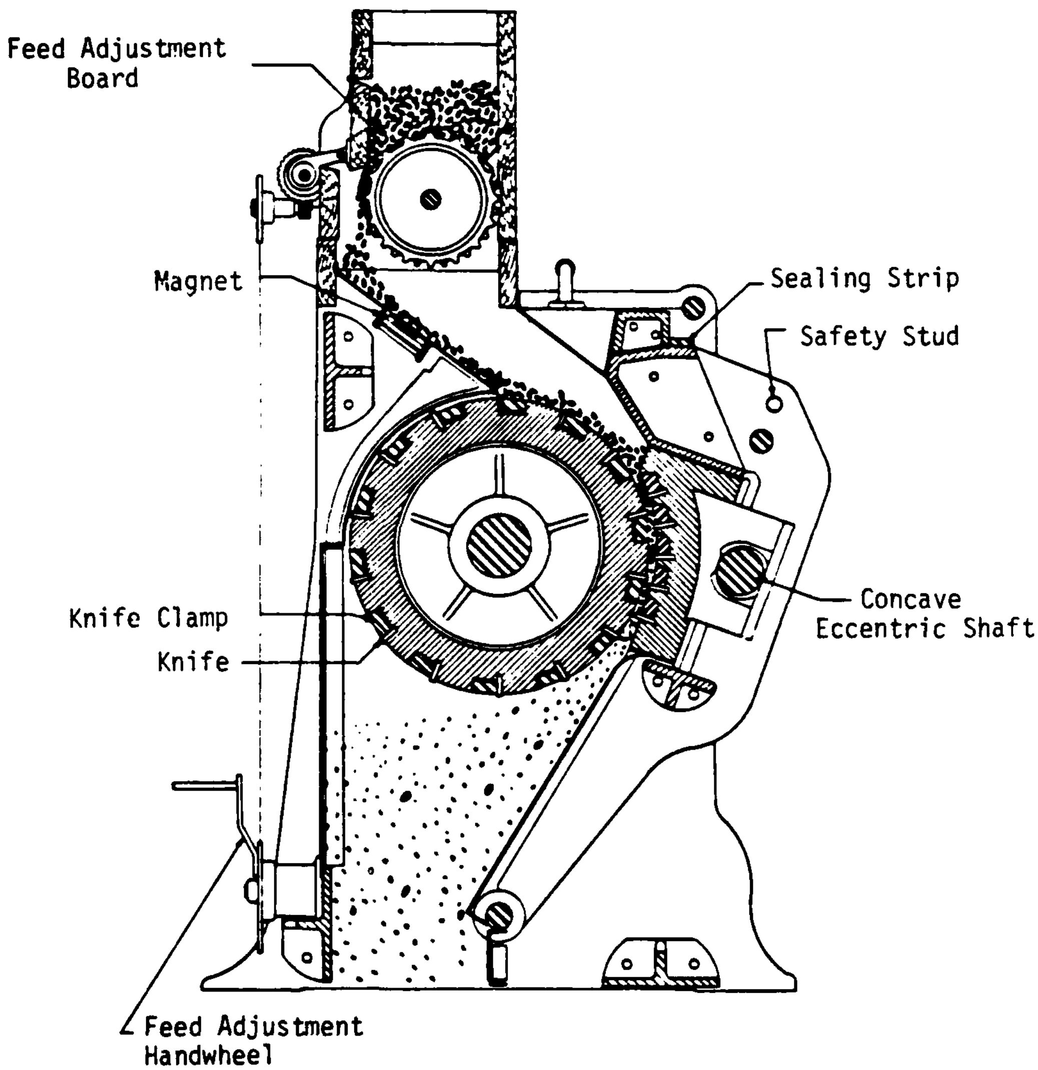

Figure 4. Cutaway to demonstrate operation of a huller (60).

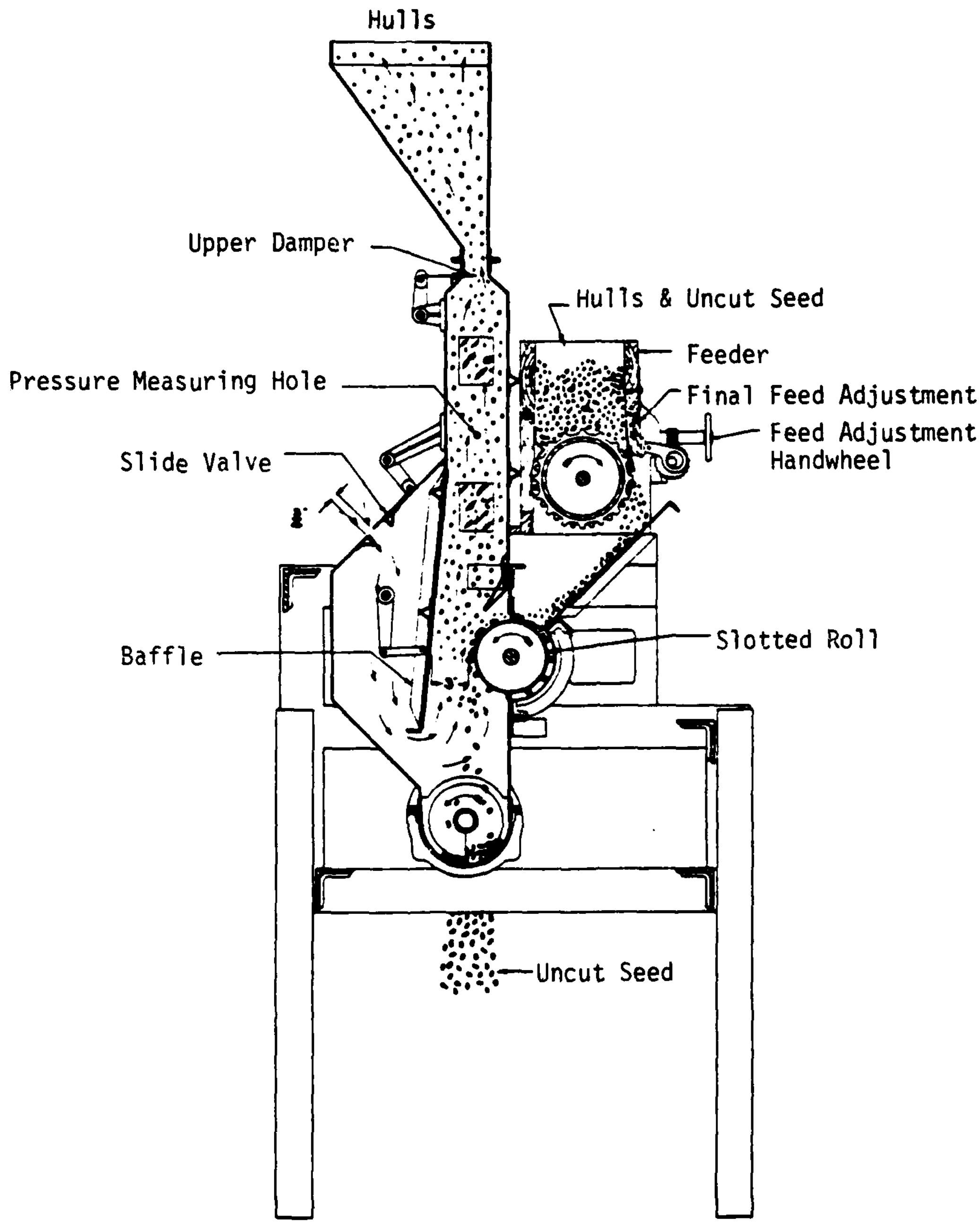

Figure 5. View to demonstrate operation of a hull and seed separator (60).

attributed to seed fragments. Brown, Piccolo, and Tripp (61) estimated that about 60 per cent of the dust in the hulling areas of five cottonseed oil mills in Texas was derived from seed kernels.

Oil Extraction and Meal Production

As the hulls are being sent to storage from the hulling and separating operation, the seed meats (kernels) start the route leading to oil extraction and meal production. The seed meats are first conditioned at a temperature of approximately 180°F in a steam cooker before being flaked (Cooked meats are rolled into flakes about 0.0001-inch thick.) (21). The very thin flakes are then conveyed to the extraction equipment (*Figure 6*) where hexane is used as the solvent to extract the cottonseed oil. First the flakes are washed with dilute miscella (solution of oil and solvent) which removes oil from the surface of the flakes and softens the oil cells inside. As the flake bed moves through the extractor a heavy miscella is recycled through the bed for additional oil extraction. This bed also acts as a filter for the oil rich miscella prior to its being pumped from the extractor to the oil-solvent separation system (62). Following removal of the oil rich miscella the flake bed passes through a series of progressively more dilute miscella washes until fresh solvent is used. Then the bed passes over a drainage area before being discharged in a semi-dry condition to the desolventizer-toaster. At this point the flakes still contain approximately 30 per cent hexane

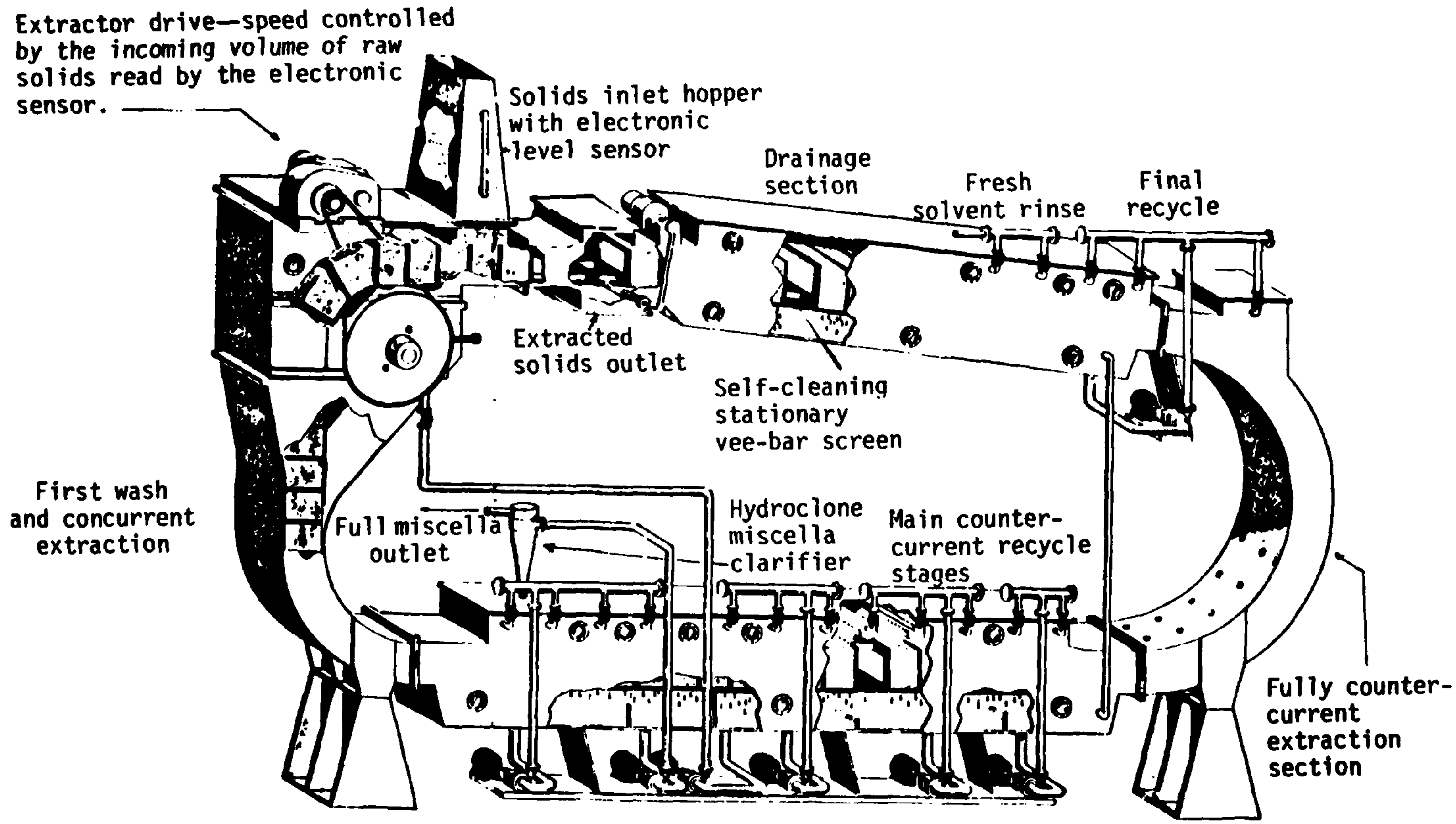

Figure 6. Schematic of a Crown solvent extractor (62).

which is removed by injecting steam as the flakes are agitated. Enough steam condenses in the flake bed to raise the moisture content to the optimum level for subsequent toasting which occurs in the lower trays of the desolventizer-toaster as the temperature of the meal increases from heat input through the steam-heated tray bottoms. Toasting destroys undesirable enzymatic activity and reduces the moisture content to provide a high quality meal. After toasting, the meal goes into a rotary steam dryer and then to a hammer mill for pulverizing. This product may be sold for feed either as meal or as pressed pellets.

Approximately 20 to 30 per cent of the oil-solvent mixture that is pumped from the solvent extractor to the oil-solvent separation system is cottonseed oil with the remainder being the hexane solvent. These two miscible liquids have widely separated boiling temperatures, which permits their separation by distillation. The miscella passes through three stages of evaporators for complete solvent removal, with the oil being subsequently alkali refined to separate the high quality oil from the soap stocks (21).

Because the products are moist and move through a closed system, oil extraction and meal production processes are the cleanest and most dust free environments in the cottonseed oil mill.

Dust Sampling

The purposes of this investigation dictated the employment of three different types of dust sampling equipment.

a) Four Lumsden-Lynch vertical elutriators, designed to selectively collect particles having aerodynamic diameters of 15 μm or less as specified in the cotton dust Standard, were employed for gravimetrically evaluating (according to standards) airborne dust concentrations and for determining size-count distributions.

b) Bendix BDX44 and Mine Safety Appliances (MSA) model S personal samplers were utilized for similarly determining dust concentrations and size-distributions but without size discrimination in order that the results of the two sampling techniques could be compared by both the amount and size-count distributions of the dust collected.

c) Staplex hi-volume samplers were employed for evaluating total airborne particulate loadings and for obtaining sufficient sample mass to permit carbohydrate and protein analyses for estimating the plant fraction of the collected dust.

The Lumsden-Lynch vertical elutriators (Figure 7) utilized in this study were manufactured by General Metal Works (63) and were composed of a Gast 115v, 60 Hz, line operated vacuum pump connected through a 0.25-inch I.D. hose to a 37-mm filter holder mounted in a ferrule on top of the

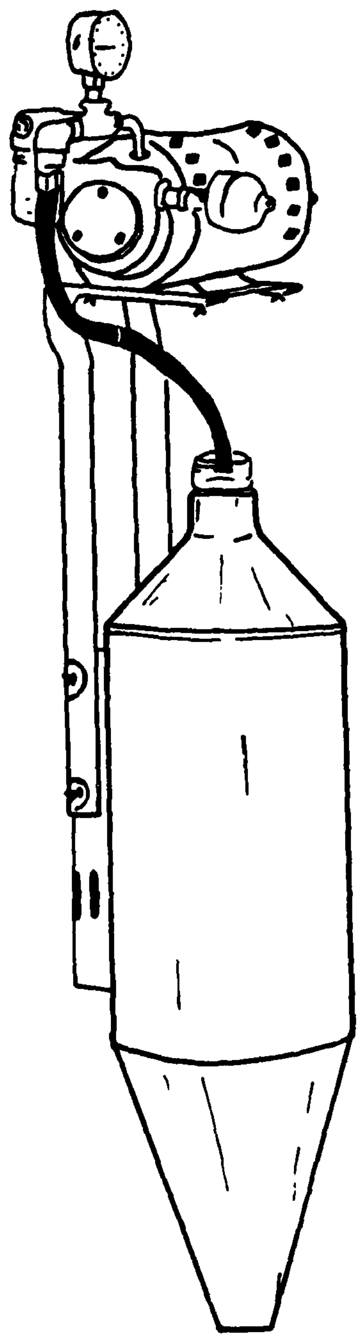

Figure 7. Lumsden-Lynch vertical elutriator by General Metal Works (63).

elutriator chamber. The latter was 6-inches in diameter and 14-inches in length with a lower conical entry section that was 10-inches high and tapered to an opening of 1.063-inches (27-mm) in diameter (64). An upper section 2.5-inches high and tapered with a ferrule extension to hold the 37-mm filter cassette completed the vertical elutriator (12) for an overall length of 26.5 inches from the opening to the bottom of the ferrule. The vacuum pump was bracket-mounted above the ferrule. Utilizing a previously calibrated Precision Scientific wet-test meter and in-line limiting orifices for determining and controlling flow rates, each of the four elutriators employed were standardized to a sampling rate of 7.4 $\pm$ 0.2 liters per minute (lpm). Dust samples were collected on 37-mm diameter, 5-μm pore size polyvinyl chloride membrane filters manufactured by Gelman Instrument Company. For handling purposes, all filters, along with their support pads, were maintained in polystyrene cassettes which mounted in the ferrule on top of the elutriator. Before and after exposure, each filter was dessicated for 24 hours prior to weighing on a Mettler Gram-Atic balance accurate to $\pm$ 10 μg.

A vertical elutriator was positioned in each of the four process areas, (a) cleaning, (b) delintering (1st-cut), (c) hulling and separating, and (d) baling. They were placed in a vertical position so that the entry ends were approximately 5 feet above the floor (standard permits 4.5 to 5.5 feet). In order to determine the dust levels and to evaluate any changes in concentration throughout the day, the samplers were operated during each of the three daily work shifts. Preliminary observations indicated that due to the excessively dusty conditions, the originally anticipated sampling time of 6 hours per shift resulted in masking of the filters, making size-count analyses impossible. It was, therefore, necessary to sample each shift with a series of three sampling periods ranging form 0.5 to 1.5 hours each.

Evaluation of the facility under a full range of operational conditions required that one application of the sampling protocol be during the summer (August) when all windows and doors were open and when the seeds being processed had been in storage for as long as a year were, therefore, at their driest stage. The sampling procedure was repeated during the obverse conditions, that is, during the winter (December) when the windows and doors were closed and when the seeds being processed had been recently delivered from the gin and were at their highest level of moisture.

Personal samplers

The BDX and MSA personal samplers were also employed during the two sampling seasons, respectively. The BDX sampler (Figure 8) consists of a case which houses a diaphragm pump assembly, dust filter, flowmeter, a flow regulator/pulsation dampener assembly, and a rechargeable battery (65). Operation of the sampler is controlled by a push-on/push-off switch located on one end of the case. The sample air inlet is located

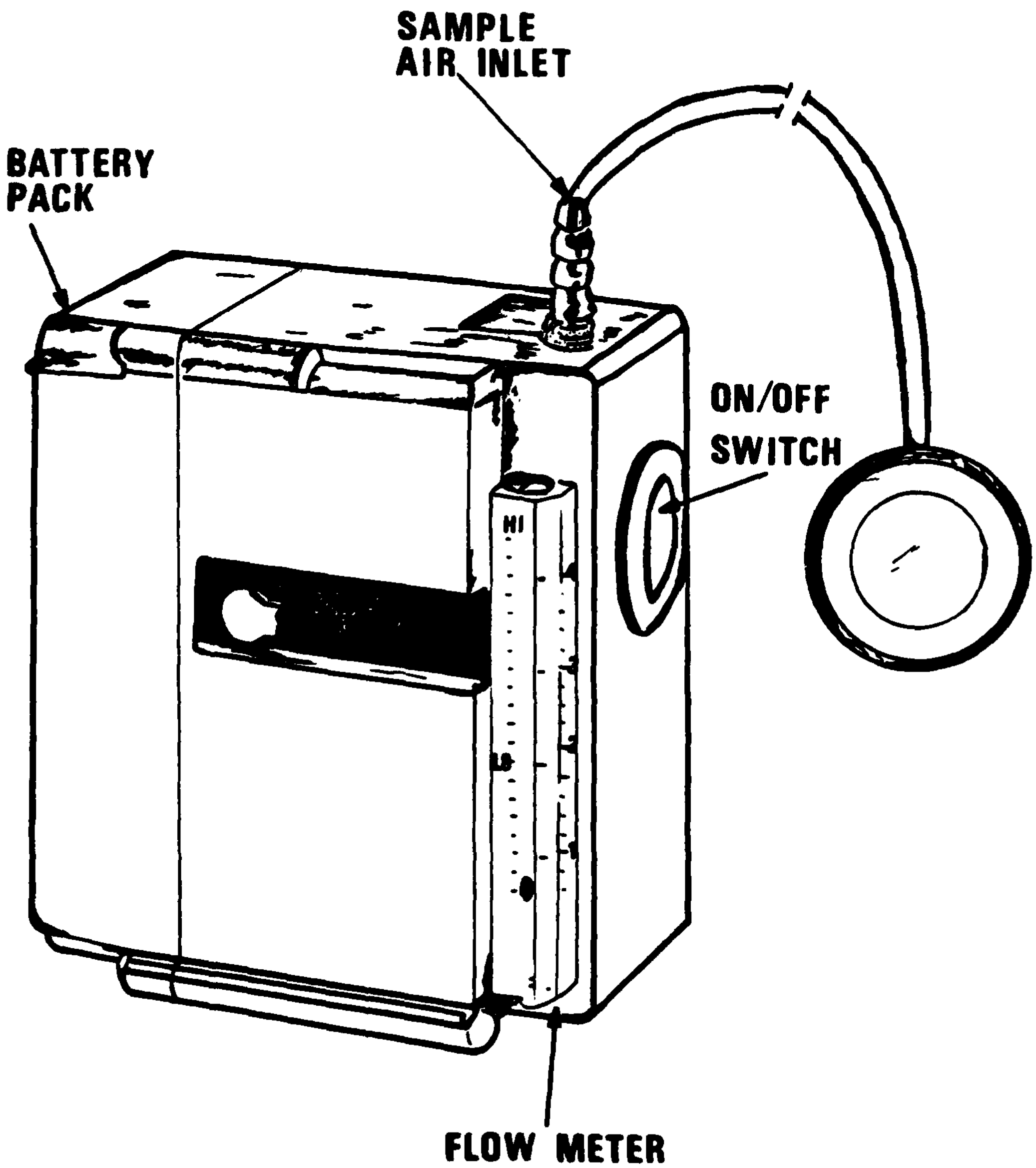

Figure 8. Bendix BDX 44 personal sampler (65).

on top of the case and accepts 0.25-inch I.D. flexible sample hose. This inlet is connected internally through a dust filter to the bottom of the flowmeter. The outlet on the flowmeter connects to the flow regulator/pulsation dampener assembly with the outlet of this adjustment assembly being connected to the inlet of the double diaphragm pump which is exhausted to the atmosphere. Rechargeable batteries permit portable operation of this sampler for 8 hours to 2 lpm with a nominal head pressure. Except for the location of the On-Off switch, both the BDX and MSA samplers are virtually identical and both types are Federally approved as permissible air samplers (65,66). A wet-test meter was also employed to calibrate these samplers at sampling rates near 2 lpm. The same types of filters, pads, and holders, and the same filter handling and gravimetric analyses were used with these samplers as with the vertical elutriators. Since personal samplers were used for the purpose of providing side-by-side comparison with the elutriators, the same areas were sampled at the same heights and for the same time periods as the elutriators but were used in stationary positions rather than worn by personnel.

Staplex hi-volume samplers

Staplex hi-volume air samplers were used to evaluate total airborne particulates in the four process areas. These samplers have 0.5-horsepower motors which operate at 115v, 60 Hz, and employ a two-stage high-speed (one speed) centrifugal fan to move the air through an 8 x 10-inch filter. Flow rate for these samplers is measured with a by-pass rotameter (67). Calibration of the hi-volume samplers was accomplished by using a series of calibration plates connected in a system to a liquid filled manometer. This system had been calibrated so that the liquid displacement in the manometer was directly related to cubic feet per minute (cfm) of air moved. By knowing the true air flow in cfm for the inches of water displaced, rotameter readings on the hi-volume samplers were graphed against true cfm for each calibration plate to provide a calibration curve for the Staplex by-pass rotameter. Preceeding and following exposure, each glass fiber sampling filter (manufactured by Gelman Instrument Company) was desicated for 24 hours before weighing on a Sartorius Type-2432 balance. These samplers were utilized in a horizontal position, 5 feet above the floor, to collect dust samples over periods ranging from 13 minutes to 73 minutes, depending on area.

Dust Analysis

Total dust collected for each sample was represented by the difference in the filter weighings before and after sampling. These values were converted to concentrations per cubic meter of air by utilizing flow rates and elapsed times during sample collections. The concentrations in $\mu g/m^3$ for the samples collected with the elutriators were compared with permissible exposure limits prescribed in the Standard and were then compared with the dust concentrations determined with the personal samplers in order to determine the effects of the elutriator on the measured level of total dust. Following gravimetric determinations, a pie shaped wedge was removed from the vertical elutriator and personal sampler filters and subjected to size-count evaluations. The wedge was placed (dust side up) on a clean glass microscope slide, glass cover-slipped, treated with a drop of immersion oil to render the filter matrix transparent, and sealed around the edges with clear fingernail polish (68). The prepared slides remained at room temperature overnight before evaluating.

Dust particles were counted and sized with an American Optical series One-Ten microscope (69) under high-dry magnification of 450x. A micrometer was placed in one of the occulars and a Porton graticule in the other. Both were calibrated against a stage micrometer (70) before being used for counting and sizing particles. The Porton graticule consists of a large rectangle with one half divided into six smaller rectangles and a series of circles of increasing size arranged along the top and bottom of the large rectangle. The portion divided into six smaller rectangles defines the area on the filter for particle counting and sizing, and the diameter of each circle is larger than the previous one by the square-root of two (71). Calibrating the Porton graticule is accomplished by comparing the 100 Porton unit scale with the stage micrometer to determine the value of a single Porton unit in μm. With this calibration, the diameter of any circle is determined by:

$d = x\sqrt{2^n}$ where

d = diameter of the circle in μm.

x = value of one Porton in μm, and

n = circle number (circles are numbered 1 through 9).

Under the magnification used in this study, one Porton unit measured 0.5 μm, resulting in a size range for the circles of 0.71 μm to 11.31 μm. For the occular micrometer, each occular unit calibrated to 2.17⁴ μm stage value.

Counting and sizing of the particles was accomplished according to the "truncated multiple traverse" procedure (72). To increase statistical validity, ten fields were counted and sized per traverse and a total of ten traverses were made per sample for a total of 100 fields. Following each traverse, the number of particles for each size interval was recorded until an accumulated count of 10 or more particles was reached; whereupon, that size interval was disregarded on subsequent traverses. After 10 traverses, the particles counted in each size interval were totaled and reduced to the number of particles per traverse by dividing the total count by the number of traverses required to reach that count. This gave an average number of particles per traverse for each size interval, which was used to determine cumulative percentages. The cumulative percentage of particles up to and including each size interval was plotted on log-normal graph paper, versus the particle size in micrometers. A best-fit straight line was drawn through the plotted points to yield information needed for calculating the geometric standard deviation (σg), median diameter (in μm) for number of particles (Mp), surface area (Ms), and mass (Mv) distributions. The calculations for these are based upon the following (72).

Geometric standard Deviation:

$$\sigma g = \frac{84.13 \text{ per cent particle size}}{50 \text{ per cent particle size}} .$$

Surface Area Median Particle Diameter:

$$Ms = \text{Log } Ms = \log Mp + 4.6\ (\log^2 \sigma g).$$

Mass Median Particle Diameter:

$$Mv = \log Mv = \log Mp + 6.9\ (\log^2 \sigma g).$$

The vertical elutriator and personal sampler were compared by using the largest inclusive particle sizes in the 99.9 per cent cumulative log-normal plots for each and statistically evaluating this information by using an independent "t" test.

Staplex hi-volume samples

Again, the difference in the before and after filter weights represented the quantity of dust collected. Since the dust was assumed to be evenly distributed over the filters, sections were removed and used for carbohydrate and protein analyses. Percentage concentrations of each were calculated for the dust by ratioing the weight of the removed section to the total (after sample collection) filter weight and determining on a proportion basis. The dust samples were analyzed in the Allergy/Pulmonary Research Laboratory, Department of Medicine, University of Oklahoma Health Sciences Center. Guidelines described in the procedure by Kahan (73) were followed for carbohydrate analysis, and the procedure for estimation of Kjeldahl nitrogen by Garvey *et al.* (74) was used for protein.

CHAPTER V

OBSERVATIONS AND DISCUSSION

Dust Concentrations

Summer

The federally specified Lumsden-Lynch vertical elutriator was used, according to guidelines in the Standard, to determine lint free "respirable" airborne dust concentrations in the mill, and to provide the mean for identifying those areas having amounts in excess of permissible exposure limits, which would indicate a potential occupational health hazard. Table 1 lists the elutriator dust collections by process, workshift, and sampling time.

The results presented in this table leave no doubt that the standard of 500 $\mu g/m^3$ was exceeded in every occupational area examined in the cottonseed oil mill studied. Heaviest loadings of airborne dust were observed in cleaning, followed by baling, with 1st-cut delintering, and hulling and separating having approximately equal but somewhat lower concentrations. At least one sample in the cleaning area was observed to have a concentration that surpassed the standard by more than a factor of 12, and the average airborne dust averaged more than 8.5 times the permissible limit

TABLE 1

DUST CONCENTRATIONS, LUMSDEN-LYNCH VERTICAL ELUTRIATOR, SUMMER SAMPLES

Process		Day Shift		Evening Shift		Night Shift	
		Sampling Time Minutes	Dust $\mu g/m^3$	Sampling Time Minutes	Dust $\mu g/m^3$	Sampling Time Minutes	Dust $\mu g/m^3$
Cleaning		61	6,156	61	4,303	51	2,665
		50	3,123	59	4,132	53	5,969
		43	3,506	53	4,521	51	4,565
	$\bar{X}$ =	51.3	4,262	57.7	4,319	51.7	4,400
1st-Cut Delintering		46	1,048	69	1,106	55	973
		42	797	57	728	57	822
		63	1,253	51	1,286	57	493
	$\bar{X}$ =	50.3	1,033	59.0	1,040	56.3	763
Hulling and Separating		55	756	63	1,406	50	1,423
		62	1,212	57	824	65	764
		51	1,263	53	1,165	57	848
	$\bar{X}$ =	56.0	1,077	57.7	1,132	57.3	1,012
Baling		44	1,739	57	1,295	55	1,416
		42	1,023	64	1,300	44	702
		45	1,522	51	1,632	56	911
	$\bar{X}$ =	43.7	1,428	57.3	1,409	51.7	1,010

for all samples collected in the cleaning process. Within a process area, dust concentrations fluctuated both during and between workshifts, with the differences being greater between individual samples on the same shift than between average concentrations from shift to shift. These differences were attributed to the frequent interruptions in the process flow of seeds, which were very apparent during the collection of samples for this study. Such disruptions are common and are viewed as normal for this type of industry; consequently, wide variations in dust levels are inherent. Of all the results listed in Table 1, only one (night shift in the 1st-cut delintering area) was within the standard and it was 98.6 per cent of the quantity allowed, probably because of a longer than usual process interruption. Results of this sampling demonstrates that conditions were present for subjecting workers to occupational exposures of airborne cotton dust in excess of the standard by a factor of approximately 2 in the 1st-cut delintering and hulling and separating processes, approximately 3 in the baling process, and, as mentioned above, approximately 8.5 in the cleaning process. The large concentrations observed in cleaning are attributed to the loose material accumulated during growing, harvesting, and storage being released to the air by the process. Of the remaining three work areas, the presence of more lint fragments was credited as the cause of slightly higher concentrations in baling than the other two processes.

An additional evaluation of dust (particles collected without size discrimination) was provided by utilizing BDX 44 personal samplers in conjunction with the vertical elutriators. These samplers were not intended to be selective in particle sizes collected and, therefore, afforded a view of the added influence on dust concentrations by the various sizes of airborne dust present, including lint. The results of these samplings are presented in Table 2.

Dust concentrations determined by the BDX 44 samplers exceeded the 500 $\mu g/m^3$ permissible exposure limit, established for elutriator samples, in every instance. These data confirmed that the work environment with the greatest average burden of airborne dust was the cleaning, with average concentrations exceeding the 500 $\mu g/m^3$ limit by a factor of approximately 18, and one sample exceeding the limit by a factor of approximately 30. Again, the baling area was the next most dusty area with average concentrations exceeding the limit by a factor of about 15, and one sample exceeding by a factor of about 34. The 1st-cut delintering, and hulling and separating followed with average concentrations exceeding that permitted by a factor of approximately 4.5 each. Concentrations of dust were approximately double those collected by the vertical elutriator in all areas except the baling process, where factors of four or more were encountered and one sample exceeded the simultaneously collected elutriator sample by a factor of 11. Greater differences in this process were probably due to heavier loadings of airborne

TABLE 2

DUST CONCENTRATIONS, BENDIX BDX 44 PERSONAL SAMPLER, SUMMER SAMPLES

Process		Day Shift Sampling Time Minutes	Day Shift Dust $\mu g/m^3$	Evening Shift Sampling Time Minutes	Evening Shift Dust $\mu g/m^3$	Night Shift Sampling Time Minutes	Night Shift Dust $\mu g/m^3$
Cleaning		61	10,513	64	7,605	53	7,188
		52	7,228	60	7,389	56	15,232
		43	7,285	53	9,645	50	9,257
	$\bar{X}$ =	52.0	8,342	59.0	8,213	53.0	10,559
1st-Cut Delintering		51	2,775	71	1,461	58	1,139
		42	2,584	-	-	-	-
		64	2,286	52	2,631	58	2,929
	$\bar{X}$ =	52.3	2,548	61.5	2,046	58.0	2,034
Hulling and Separating		59	1,853	68	2,708	52	2,392
		69	1,803	58	1,884	67	1,634
		52	3,540	54	3,317	57	2,096
	$\bar{X}$ =	60.0	2,399	60.0	2,636	58.7	2,041
Baling		50	12,500	68	8,154	58	6,564
		44	6,087	60	7,473	49	2,591
		46	17,075	51	5,437	58	3,322
	$\bar{X}$ =	46.7	11,887	59.7	7,021	55.0	4,159

lint, but even with the older standard of 1,000 $\mu g/m^3$ "raw" cotton dust, all workshifts in all process areas would have been out of compliance, with the cleaning and baling processes reaching levels as high as 15,000 and 17,000 $\mu g/m^3$, respectively. Fluctuations in dust concentrations, similar in pattern to those collected by the elutriators, were also observed for these samplers and could be attributed to interruptions in the flow of seeds.

Staplex hi-volume samplers were utilized for short periods in each area in order to estimate total airborne particulate loadings. The results of these evaluations indicate the following levels.

Cleaning Process	1st-Cut Delintering
22,630 $\mu g/m^3$	4,740 $\mu g/m^3$
Hulling and Separating	**Baling**
2,119 $\mu g/m^3$	55,330 $\mu g/m^3$

Because of the extremely high concentrations, samples collected in this manner were difficult to maintain on the large filter, even with short collection periods; therefore, total particulate matter may have been even higher than reported.

These results verify that an occupational environment, heavily laden with airborne dust and particulate matter existed in the process areas examined and that even though these levels were well above the recommended permissible limit, the vertical elutriator may have been, in fact, understating the total dust concentration by a factor of at least 2.

Winter

The sampling protocol was repeated in December in order to define dust conditions while processing new crop seeds versus the Summer processing of stored seeds. It was visually apparent that there were more work interruptions and less airborne dust than had been observed during the summer sampling, and this was generally confirmed by the results from the three sampling procedures.

Again, elutriator samples (Table 3) demonstrated heaviest loadings of airborne dust in cleaning; however, this time, 1st-cut delintering came next with concentrations averaging just slightly more than hulling and separating, and baling which were approximately equal. One of the cleaning samples exceeded the standard by a factor of 8, with the average concentrations exceeding the permissible limit by a factor of 6 for the day shift and by a factor of 2 for the evening shift; however, the night shift average was in compliance with the standard. The other three processes were out of compliance with the permissible limit by a factor of 1.5 to 2.0 for the day and evening shifts, but were also within the limits for the night shift. Approximately 39 per cent of all samples collected during this period were within permissible limits; however, most of these were taken during the night shift when the relative

TABLE 3

DUST CONCENTRATIONS, LUMSDEN-LYNCH VERTICAL ELUTRIATOR, WINTER SAMPLES

Process		Day Shift		Evening Shift		Night Shift	
		Sampling Time Minutes	Dust $\mu g/m^3$	Sampling Time Minutes	Dust $\mu g/m^3$	Sampling Time Minutes	Dust $\mu g/m^3$
Cleaning		49	3,995	32	1,083	41	65
		41	3,681	36	556	38	561
		37	1,978	30	1,422	44	182
	$\bar{X}$ =	42.3	3,218	32.7	1,020	41.0	269
1st-Cut Delintering		60	754	35	1,103	40	266
		40	1,262	66	504	36	111
		31	1,245	30	796	59	135
	$\bar{X}$ =	43.7	1,087	43.7	801	45.0	170
Hulling and Separating		65	574	30	933	40	267
		41	747	36	481	39	478
		35	837	30	711	36	333
	$\bar{X}$ =	47.0	719	32.0	708	38.3	359
Baling		62	1,272	32	460	40	468
		40	468	36	595	37	253
		33	607	30	580	48	139
	$\bar{X}$ =	45.0	782	32.7	545	41.7	287

humidity was higher and when more interruptions than usual were occurring. In fact, concentrations decreased with each succeeding shift (believed to be the result of increasing work stoppages, and/or humidity).

Results of the dust samples collected by the MSA personal samplers during December appear in Table 4. The data reflect that the permissible limit of exposure established for the elutriator was exceeded in all cases. Had the 1000 $\mu g/m^3$ permissible limit been applied, then six of these samples would have been acceptable. Cleaning was observed to have the heaviest burden of airborne dust, with one sample exceeding the standard by a factor of 22 and the average concentration for all three shifts exceeding the standard by a factor of approximately 6.3. Baling followed as the next dustiest area with the three shift average exceeding the standard by a factor of approximately 6.1, with hulling and separating coming next and exceeding the standard by a factor of approximately 3.6, and then the 1st-cut delintering with an average in excess of the standard by a factor of approximately 2.9 as the lowest of the processes evaluated. The day shift was the dustiest for cleaning and baling with the evening shift being the dustiest for 1st-cut delintering, and hulling and separating. The night shift was the least dusty for all processes evaluated. Again, these samplers did not discriminate in the particle sizes collected, and again the observed concentrations were approximately double or more the elutriated samples. One MSA sample from the baling

TABLE 4

DUST CONCENTRATIONS, MSA PERSONAL SAMPLER, WINTER SAMPLES

Process		Day Shift		Evening Shift		Night Shift	
		Sampling Time Minutes	Dust $\mu g/m^3$	Sampling Time Minutes	Dust $\mu g/m^3$	Sampling Time Minutes	Dust $\mu g/m^3$
Cleaning		49	11,188	34	3,281	45	754
		41	10,520	37	1,966	39	1,491
		37	4,980	29	3,177	43	564
	$\bar{X}$ =	42.3	8,896	33.3	2,808	42.3	936
1st-Cut Delintering		Sampler	Problem	34	4,113	43	1,010
		Sampler	Problem	73	2,516	38	888
		31	1,268	30	2,412	59	572
	$\bar{X}$ =	31.0	1,268	45.7	2,259	46.7	823
Hulling and Separating		67	884	33	2,072	44	1,035
		41	1,335	37	1,478	41	2,556
		35	1,536	30	3,797	36	1,519
	$\bar{X}$ =	47.7	1,252	33.3	2,449	40.3	1,703
Baling		61	5,565	34	1,879	44	2,679
		38	3,622	37	4,250	39	631
		Sampler	Problem	29	2,542	48	1,947
	$\bar{X}$ =	49.5	4,594	33.3	2,890	43.7	1,752

area surpassed its elutriator counterpart by more than 12 times with the collection of lint by the former probably accounting for most, if not all of the difference. Similar fluctuations in airborne dust occurred with the personal samplers as was observed with the vertical elutriators and are also attributable to interruptions in the flow of seeds and/or the high relative humidity.

Staplex hi-volume collected samples were again utilized to estimate total dust concentrations and indicated the following airborne particulate levels.

Cleaning Process	1st-Cut Delintering
11,250 $\mu g/m^3$	8,870 $\mu g/m^3$
Hulling and Separating	**Baling**
1,780 $\mu g/m^3$	7,850 $\mu g/m^3$

Even though these samplers were operated for very short periods of time, they correlated with visual observations and reflect the dusty environmental conditions present.

In summary, under the seed and weather conditions encountered during the winter sampling sequence, the average dust levels observed exceeded the permissible limit in all process areas examined for at least two of the three daily shifts. Again, the vertical elutriator appears to have under-reported the total dust concentrations by a factor of at least two. Whether or not this difference between the two sampling procedures was due to the discrimination against nonrespirable particles by the vertical elutriator will be examined by an analysis of the particle size-count distributions obtained from the two sampling procedures.

Summer/Winter Comparisons

Tables 5 and 6 provide seasonal comparisons for the elutriators and personal samplers utilized during this investigation. Table 5 offers comparisons for the elutriator collected samples by incorporating average quantities collected by area and shift, and Table 6 similarly treats the personal sampler data. Though concentrations determined by both types of samplers generally decreased with each succeeding shift during December, the overall pattern for airborne dust was obviously less with the green seeds than with the older, drier seeds in August, even though the closed windows and doors allowed less natural ventilation and tended to confine the dust inside the process areas in the winter.

Based upon the data reflected in Table 5, average airborne dust concentrations, collected by the Lumsden-Lynch vertical elutriator, in the occupational environment of all processes during all work shifts of summer sampling exceeded that observed for the same areas and work shifts during the winter by a factor of approximately 2.3, and, also exceeded the permissible limit in all areas for all shifts during the summer. Dust levels were lower during the winter for all areas and shifts than during the summer, with the greatest reduction

TABLE 5

COMPARISON OF SUMMER AND WINTER DUST CONCENTRATIONS, AVERAGES FOR LUMSDEN-LYNCH VERTICAL ELUTRIATORS

Process	Work Shift	Summer Dust $\mu g/m^3$	Winter Dust $\mu g/m^3$
Cleaning	Day	4,262	3,218
	Evening	4,319	1,020
	Night	4,400	269
1st-Cut Delintering	Day	1,033	1,087
	Evening	1,040	801
	Night	763	171
Hulling and Separating	Day	1,077	719
	Evening	1,132	708
	Night	1,012	359
Baling	Day	1,428	782
	Evening	1,409	545
	Night	1,010	287
	$\bar{X}$ =	1,907	831

TABLE 6

COMPARISON OF SUMMER AND WINTER DUST CONCENTRATIONS, AVERAGES FOR BDX AND MSA PERSONAL SAMPLERS

Process	Work Shift	Summer Dust $\mu g/m^3$	Winter Dust $\mu g/m^3$
Cleaning	Day	8,342	8,896
	Evening	8,213	2,808
	Night	10,559	936
1st-Cut Delintering	Day	2,548	1,268
	Evening	2,046	2,259
	Night	2,034	823
Hulling and Separating	Day	2,399	1,252
	Evening	2,636	2,449
	Night	2,041	1,703
Baling	Day	11,887	4,594
	Evening	7,021	2,890
	Night	4,159	1,752
	$\bar{X}$ =	5,324	2,636

occurring in cleaning. This was attributed to the change from dry, stored seeds and low humidity to the "green," new crop seeds, and the high humidity during the winter sampling. Cleaning, however, demonstrated the greatest concentrations of dust for both seasons, as would be expected, since this is where most of the extraneous material, collected during growing, harvesting, and transporting will be separated from the seeds. Average concentrations for all Lumsden-Lynch samples (Table 5) collected on the night shift during the winter sampling reflect that every process would have been in compliance with the final cotton dust standard. This was the only time during elutriator sampling that a single process, much less all four, averaged less than 500 $\mu g/m^3$ during a shift. As previously stated, however, operating conditions and/or weather contributed to reduced airborne dust.

As with the Lumsden-Lynch samplers, the airborne dust collected by the personal samplers (Table 6) during the summer exceeded the winter concentrations by a factor of approximately 2.0, based on the average concentrations for all areas and all shifts. Again, the cleaning process demonstrated the greatest concentrations for both seasons and was attributed to this being the area where most of the extraneous material accumulated during growing, harvesting, and transporting was separated from the seeds. Baling was the next dustiest area for both seasons, probably due to the addition of lint. The other two processes were approximately equal to each other in concentrations for each season, except for the winter night shift where hulling and separating doubled the concentration for 1st-cut delintering. Similar to the elutriators, the winter night shift reflected the lowest concentrations observed throughout the study for personal samplers, and was attributed to the same reasons for the reduced elutriator concentrations during this time. So, the data presented in Table 6 are supportive of the elutriator dust pattern, including the observation that the processing of green seeds during winter generated lower quantities of airborne dust, and the winter night shift concentration averages were the lowest observed during the study.

The average dust concentration for the four process areas collected by the Staplex hi-volume sampler was 21,205 $\mu g/m^3$ for the summer and 7,438 $\mu g/m^3$ for the winter, thus the summer average exceeded the winter average by a factor of approximately 2.85. This was further support for the seasonal differences observed with the elutriators and personal samplers.

Size-Count Distributions

Because byssinosis is a disease of the pulmonary system, one of the most critical characteristics of cotton dust is the particle size distribution and the extent to which this property influences dust penetration into the respiratory system; therefore, following dust concentration measurements, the samples were evaluated microscopically to determine the count and size range of particles sampled by each procedure.

Summer

In accordance with the previously described "truncated multiple traverse" procedure, samples collected by the vertical elutriator were evaluated for each shift and each process. Typical size-count data (represented by a vertical elutriator sample collected on the day shift in the cleaning area) are graphically portrayed in Figure 9. This evaluation revealed that workers in every area studied were not only occupationally exposed to dust concentrations exceeding the 500 $\mu g/m^3$ permitted, as reported earlier, but that greater than 99 per cent of this dust (according to size-count) would be respirable if particles 15 μm (intended size cut-off for elutriator) or less in diameter are accepted as being respirable. More than 98 per cent of all the particles observed in the size-count evaluations in all areas on all shifts would be respirable if the upper size limit accepted were reduced to particles of 10 μm diameter or less. Even though most of the particles observed for all samples were in the respirable range and even though the largest particle included in the 99.9 cumulative percentage for any sample was 19.6 μm, some were observed in every sample that were much larger than 15 μm, thus indicating that the vertical elutriator did, in fact, collect particles larger than 15 μm in diameter and, therefore, biases the results toward the nonrespirable size ranges. This indicates that the vertical elutriator collected particles larger than the stated claim, which not only makes the use of the sampling device

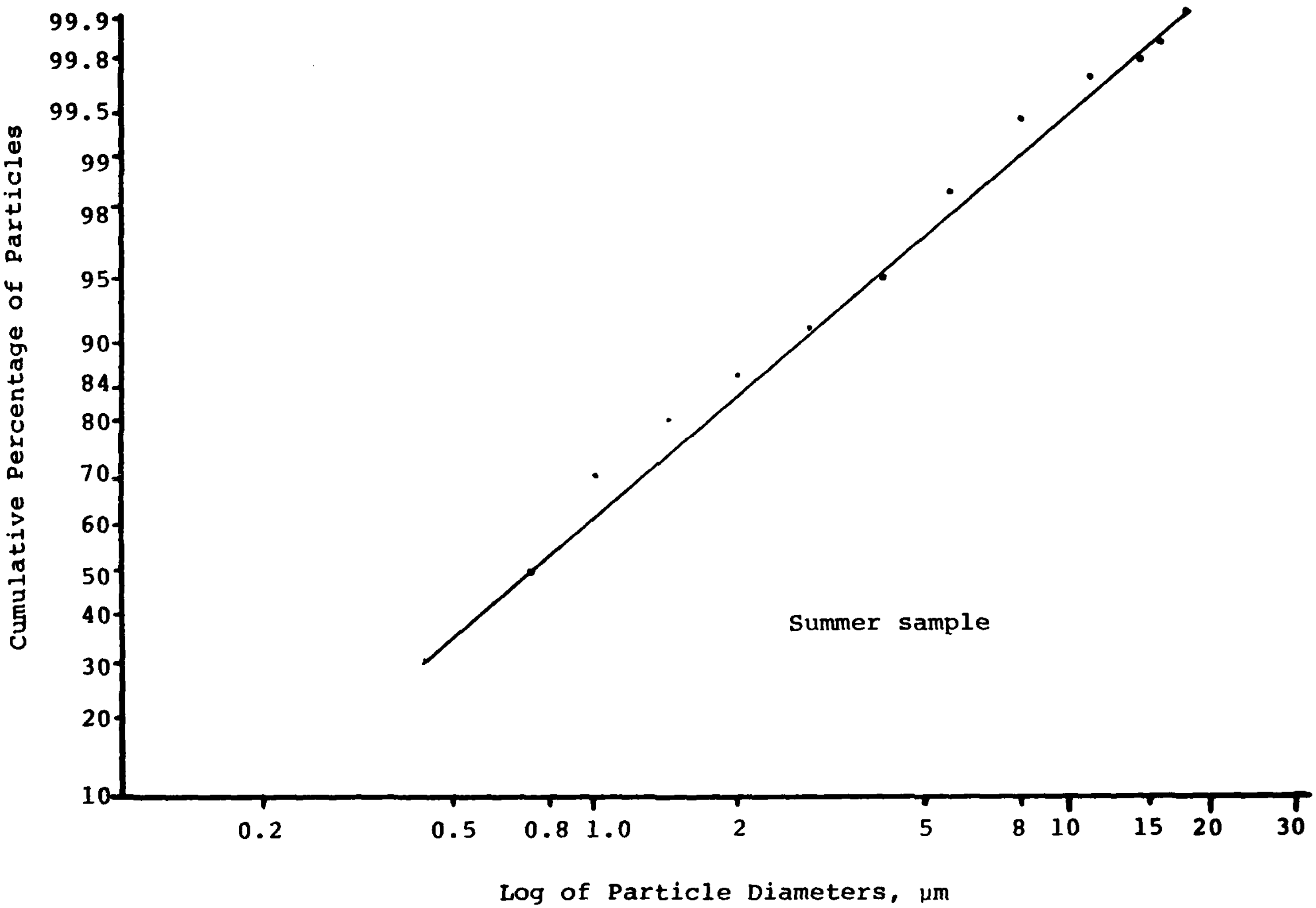

Figure 9. Size-count distribution, cleaning process, day shift, collected by a Lumsden-Lynch vertical elutriator.

suspect for monitoring respirable particles, but also, could have extensive legal and economic impacts should the standard be enforced.

In addition to including particles as large as 18 μm in the 99.9 cumulative percentage (Figure 9), this sample also demonstrated a slight convex shaped curve for the plotted points, possibly representing a distribution of particles that were less than 4 μm in diameter. Because the convex phenomenon occurred in almost all samples, it suggested the presence of two dust distributions, possibly one of soil origin and one of plant origin. This would be a reasonable assumption since the standard specifically includes dust of a heterogeneous mixture (7). This peculiarity was more prominent in some samples than others.

Should byssinosis be a response that could be associated with particle surface area and/or mass as well as size, then the distributions determined and graphed for particle surface area and particle mass (Figure 10) for the cleaning area elutriator sample would provide information needed to evaluate the occupational conditions. Because particles that are 5 μm in diameter or less are conventionally accepted as respirable (25,75) and those of 10 μm are accepted as the upper limit for health concern (71), each of the distributions was marked at the 10 μm intersection. Utilizing this as the upper limit of concern reflects that 79 per cent of the particles (Figure 10), according to surface, and 44 per cent, according to mass, fall

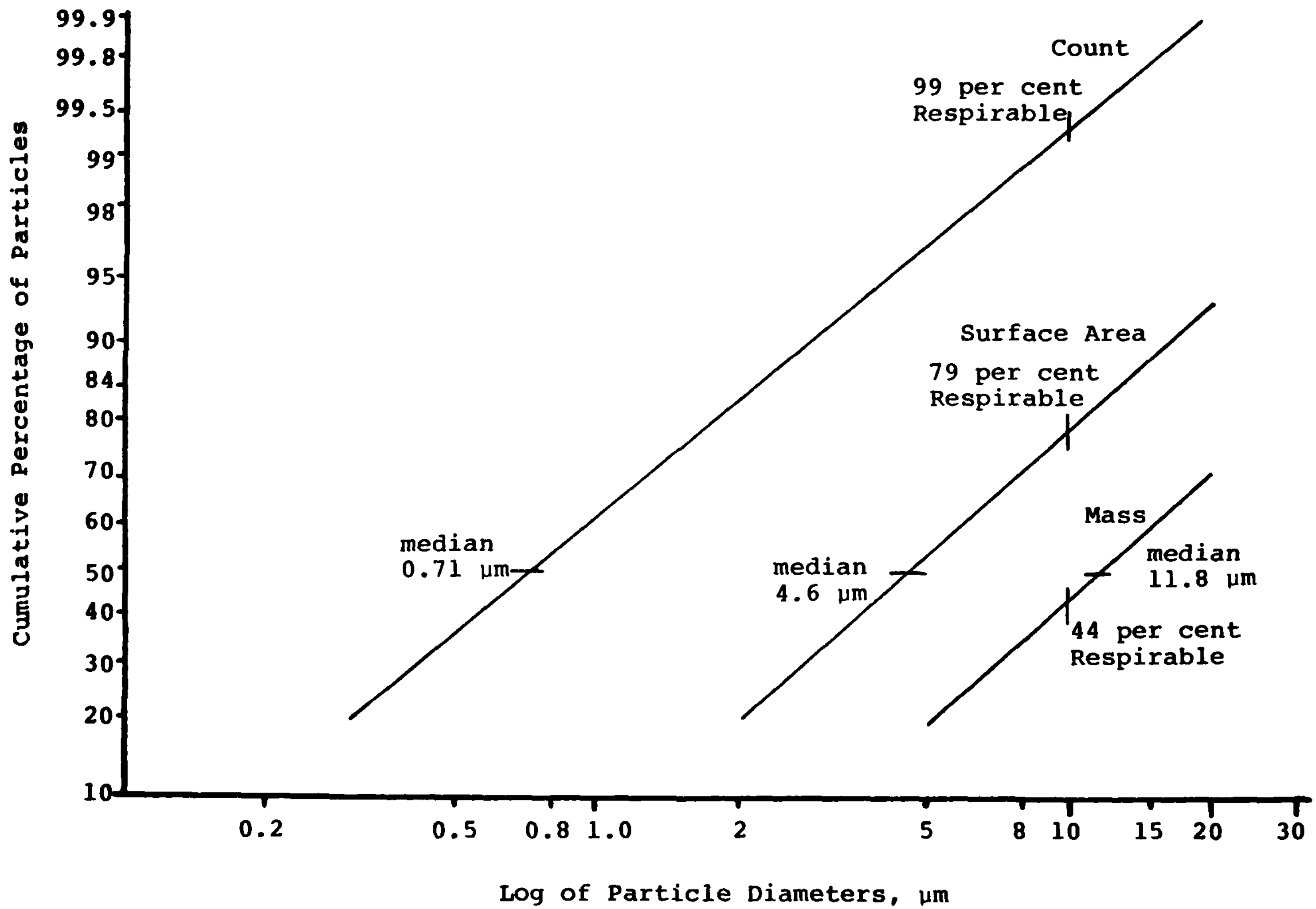

Figure 10. Size-count, surface area, and mass distributions of dust sampled by the Lumsden-Lynch vertical elutriator in the cleaning process during Summer operation.

in the hazard category. This last observation is especially significant for it indicates that less than half of the total mass of airborne dust was in the respirable size range. This implies the need for a more appropriate standard (i.e., one based on respirable dust) and/or a more appropriate sampling procedure (i.e., one which will effectively discriminate against nonrespirable particle sizes). The remaining size-count, surface, and mass distributions for the elutriator samples were translated into median particle sizes and geometric standard deviations, and presented in Table 7 from which the high degree of uniformity among the process areas and shifts may be seen.

As with dust concentrations, samples collected by the Bendix BDX 44 personal samplers were size-counted for particle distribution (typified in Figure 11), so comparisons could be made with the matching elutriator. As previously discussed, personal sampler dust concentrations were approximately double or more that of their matching elutriated sample; however, a comparison of figures 9 and 11 indicate that they followed the same pattern of size-count distribution in that more particles occurred in each size interval for the BDX sampler, but the cumulative percentages and largest 99.9 per cent inclusive particles remained very similar for the two types of samplers. The workers, therefore, appear to have been exposed to an even larger amount of respirable dust than was indicated by the elutriator samples. Again, as with the

TABLE 7

MEDIAN PARTICLE SIZE AND GEOMETRIC STANDARD DEVIATION FOR SIZE-COUNTS, SURFACE AREA, AND MASS DISTRIBUTIONS, LUMSDEN-LYNCH VERTICAL ELUTRIATOR, SUMMER SAMPLES

		Day Shift			Evening Shift			Night Shift		
Process		Count	Surface	Mass	Count	Surface	Mass	Count	Surface	Mass
Cleaning	Mp =	0.80	5.23	12.78	0.85	5.48	13.95	0.84	4.52	10.49
	σg =	2.60	2.60	2.60	2.62	2.62	2.62	2.50	2.50	2.50
1st-Cut Delintering	Mp =	0.75	4.95	13.44	0.83	4.32	9.92	0.82	4.49	10.66
	σg =	2.63	2.63	2.63	2.48	2.48	2.48	2.37	2.37	2.37
Hulling and Separating	Mp =	0.84	3.91	8.47	0.82	4.49	10.54	0.82	4.28	9.81
	σg =	2.41	2.41	2.41	2.52	2.52	2.52	2.48	2.48	2.48
Baling	Mp =	0.83	5.36	13.81	0.83	5.32	13.52	0.84	5.19	13.18
	σg =	2.61	2.61	2.61	2.63	2.63	2.63	2.58	2.58	2.58

Mp = Median particle size
σg = Geometric standard deviation

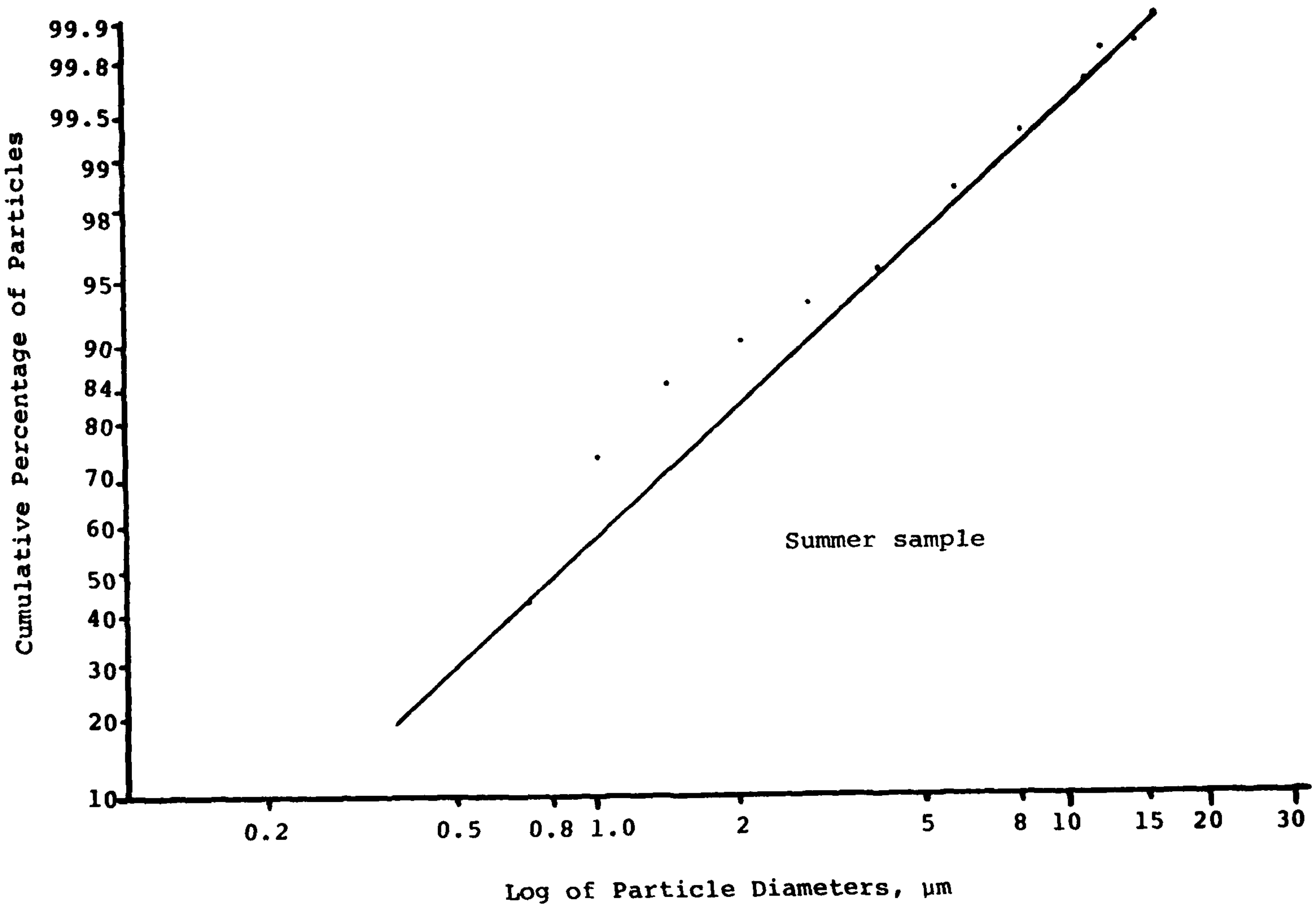

Figure 11. Size-count distribution, cleaning process, day shift, collected by a Bendix BDX 44 personal sampler.

elutriator samples, greater than 99 per cent of the dust (according to size-count) collected by these personal samplers in all areas on all shifts would have been respirable if particles 15 μm or less in diameter were accepted as respirable, and more than 98 per cent if the upper size limit of respirable particles were limited to 10 μm in diameter or less. Particles greater than 15 μm were also observed in all of these samples, with the largest particle included in the 99.9 cumulative percentage for any sample being 19.3 μm, though larger particles were often observed.

The largest particle included in the 99.9 cumulative percentage for the sample represented in Figure 11 was 16 μm. This sample also demonstrated a convex bulge for the particles less than 4 μm in diameter, which was more pronounced than that portion of the plot for the vertical elutriator counterpart sample. This more prominent display was probably due to the presence of more particles in each size interval for the Bendix samples but, in any case, the possible presence of distributions of different materials is suggested.

Similar to the elutriator sample, distributions for the BDX sample were also graphed for particle surface and particle mass (Figure 12). According to the surface area, 76 per cent of the particles would have been in the health hazard category and 37 per cent would have been in this category according to mass, if 10 μm were the upper size limit considered. The remaining size-count, surface, and mass distributions (BDX

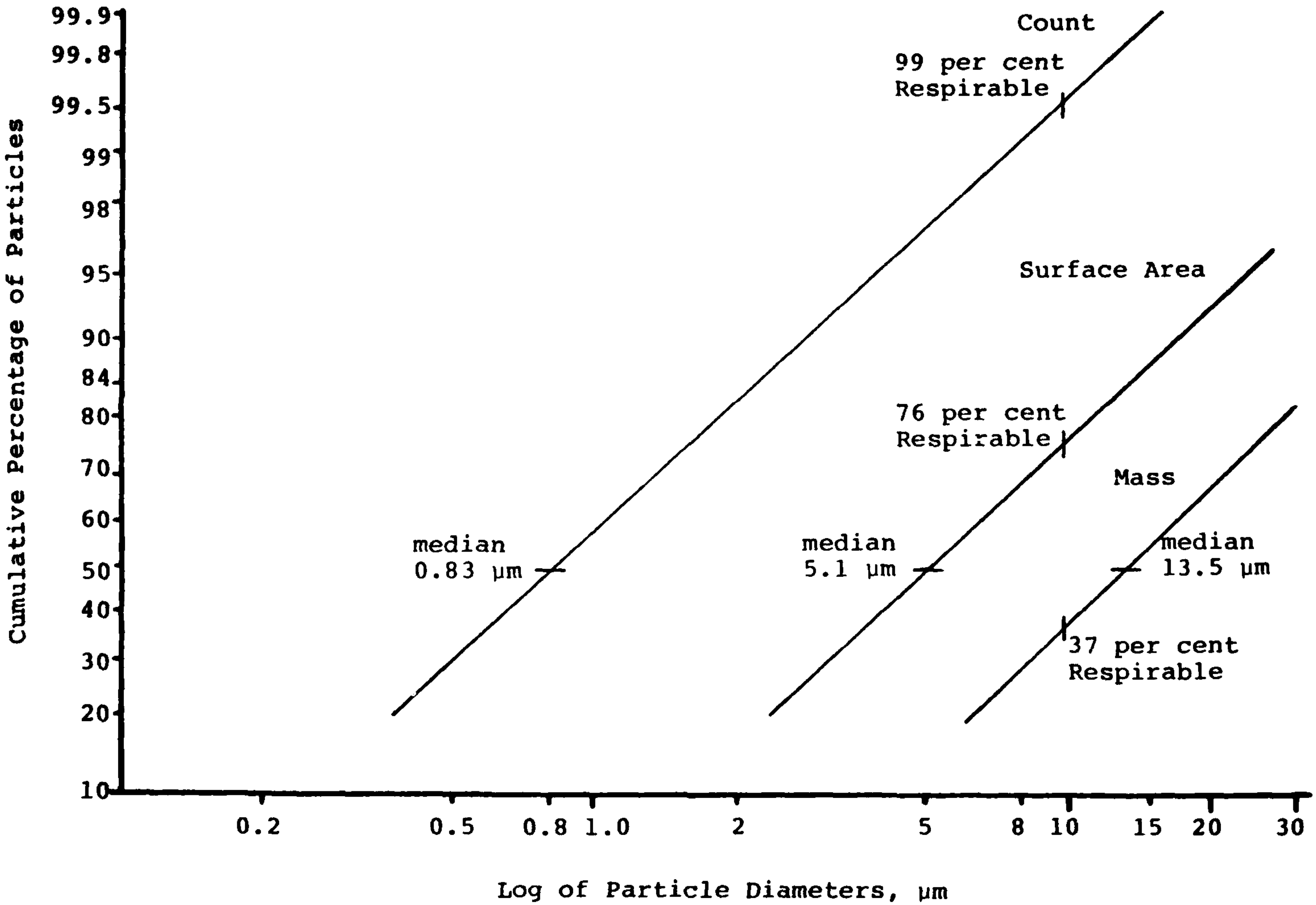

Figure 12. Size-count, surface area, and mass distributions of dust sampled by a Bendix BDX 44 personal sampler in the cleaning process during Summer operation.

samples) were translated into median particle sizes and geometric standard deviations (Table 8), which again reveal a high degree of uniformity from process to process and shift to shift.

In general, these data support the need for a more appropriate sampling procedure and/or standard.

Comparisons for size-count distributions between the Lumsden-Lynch vertical elutriator and the Bendix BDX 44 personal sampler were accomplished by using the largest particle size included in the 99.9 cumulative percentage of particles counted, sized, and graphed on log-normal paper for each sample (Table 9). Not only were some of the included particles for the personal samplers greater than 15 μm, but so were the included particles for the Lumsden-Lynch vertical elutriator.

Table 9 reveals that the mean diameter particle size for the largest (99.9 per cent cumulative) inclusive particles collected in the Lumsden-Lynch samples was 15.4 μm, and 14.1 μm for the particles collected by the Bendix sampler. Variations did occur for the largest included particles collected in the same process area by the same sampler; however, this was probably due to the fluctuations in the quantities of seeds being processed. Both sampler types demonstrated that the largest inclusive particles occurred in baling, followed by cleaning, then hulling and separating, with 1st-cut delintering last. The larger particles in baling could be due to lint

TABLE 8

MEDIAN PARTICLE SIZE AND GEOMETRIC STANDARD DEVIATION FOR SIZE-COUNTS, SURFACE AREA, AND MASS DISTRIBUTIONS, BENDIX BDX 44 PERSONAL SAMPLER, SUMMER SAMPLES

Process		Day Shift			Evening Shift			Night Shift		
		Count	Surface	Mass	Count	Surface	Mass	Count	Surface	Mass
Cleaning	Mp =	0.82	5.14	13.51	0.85	4.35	9.85	0.82	5.00	12.37
	σg =	2.60	2.60	2.60	2.47	2.47	2.47	2.59	2.59	2.59
1st-Cut Delintering	Mp =	0.84	4.49	9.52	0.81	3.80	8.23	0.83	3.78	8.10
	σg =	2.38	2.38	2.38	2.59	2.59	2.59	2.39	2.39	2.39
Hulling and Separating	Mp =	0.81	4.15	9.39	0.83	5.07	12.52	0.83	3.73	7.90
	σg =	2.47	2.47	2.47	2.59	2.59	2.59	2.38	2.38	2.38
Baling	Mp =	0.86	6.45	17.70	0.83	4.64	10.97	0.85	4.75	11.24
	σg =	2.73	2.73	2.73	2.53	2.53	2.53	2.53	2.53	2.53

Mp = Median particle size
σg = Geometric standard deviation

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DUST EVALUATION IN THE COTTONSEED OIL INDUSTRY.(U)

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TABLE 9

COMPARISON OF THE LUMSDEN-LYNCH VERTICAL ELUTRIATOR AND THE BENDIX BDX 44 PERSONAL SAMPLER, SIMULTANEOUS SAMPLING, SUMMER

Process	Shift	Largest Diameter Particles Included in 99.9 per cent Cumulative Particle Counts	
		Lumsden-Lynch µm	Bendix µm
Cleaning	Day	18.0	16.0
	Evening	15.5	13.1
	Night	15.5	15.3
1st-Cut Delintering	Day	12.3	11.7
	Evening	14.0	12.1
	Night	12.4	12.2
Hulling and Separating	Day	13.1	13.1
	Evening	15.0	15.5
	Night	15.0	12.0
Baling	Day	18.0	19.3
	Evening	16.8	13.8
	Night	19.6	15.5
	$\bar{X}$ =	15.4	14.1
	SD =	2.322	2.254

being collected by both samplers and the larger particles collected in cleaning could be due to most of the accumulated extraneous material being separated from the seeds at this point, and the larger particles in hulling and separating may be due to the dust generated by cracking the hulls and separating them from the seed meats. The smaller inclusive particles found in 1st-cut delintering may be due to most of the extraneous material having already been removed prior to this point. The data in Table 9 were evaluated for any significant difference between the two types of samplers by using the means of the largest particles included for each sampler and performing an independent sample "t test." At a level of significance of 0.05 and 22 degrees of freedom, there was no significant difference between the two samplers regarding large particle collection.

To further demonstrate the similarities on a side-by-side basis, the size-count distributions for the two samples collected in the cleaning process on the day shift (Figures 9 and 11) were used to prepare an overlay, which is presented in Figure 13. The largest 99.9 per cent inclusive particles for the Lumsden-Lynch and the Bendix samples were 18 μm and 16 μm, respectively. Of the 34 samples collected by vertical elutriator during the summer and subjected to particle size-count analysis, 32 reflected particles greater than 21 μm in diameter and the other two had particles in the 19- to 21 μm diameter interval, even though the number counted in these

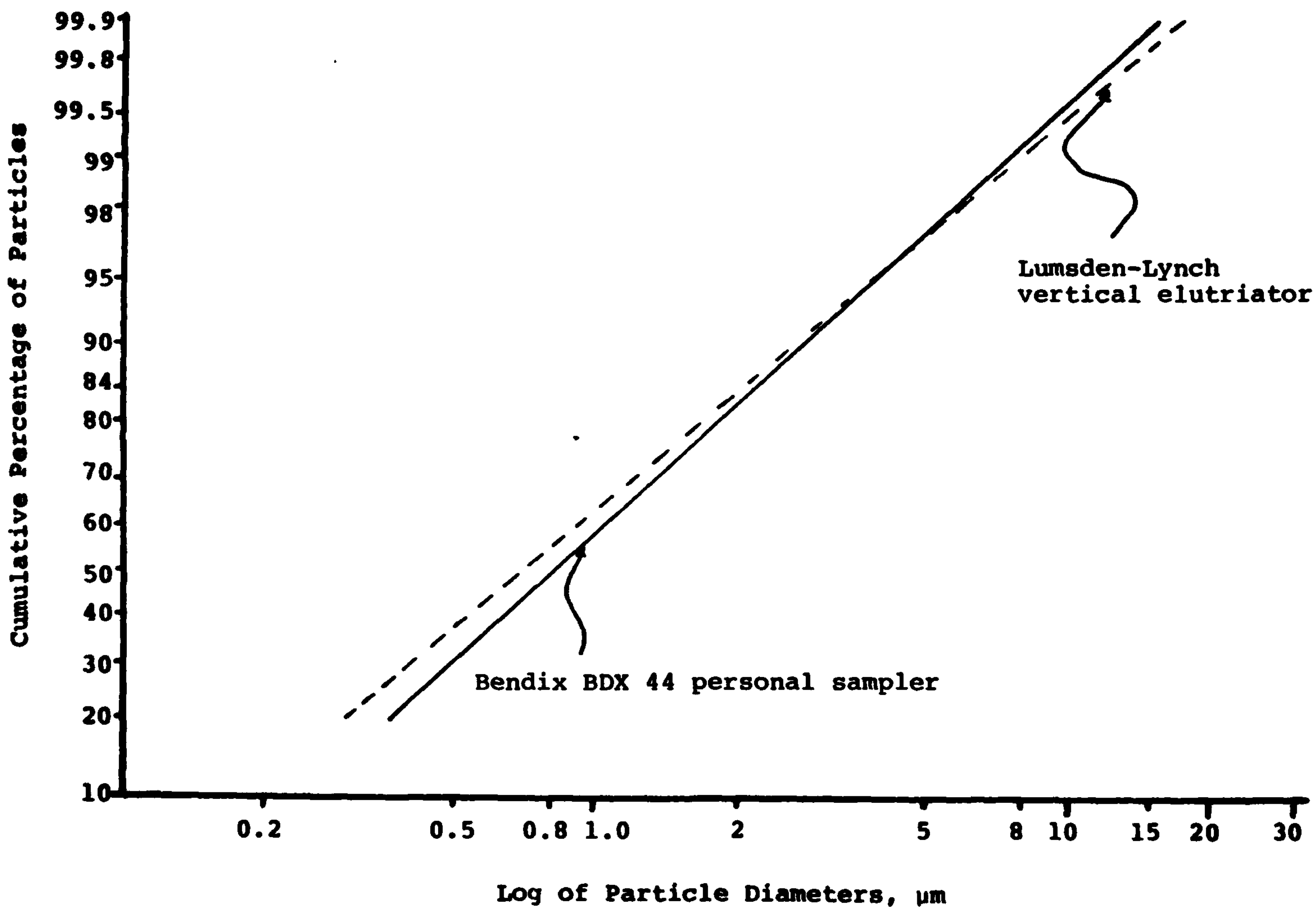

Figure 13. Size-count distributions of dust from the day shift samples collected in the Cleaning process during Summer sampling.

sizes were not included in the 99.9 per cent cumulative counts. Observations of particles this large (collected by Lumsden-Lynch vertical elutriator) would not be inconsistent with the findings of Classen (12) who determined that spheres with diameters as large as 27 μm were able to ascend the elutriator.

These observations illustrate that the vertical elutriator failed to selectively exclude particles larger than 15 μm and, in fact, presented overall size-count distributions not appreciably different from those collected without size discrimination. Since a relatively small number of comparatively large particles can represent a disproportionate mass and since the permissible limit is a gravimetric standard, the failure of the elutriator to exclude particles larger than 15 μm represents a serious sampling bias. This plus the observations which indicated that the vertical elutriator understated the dust concentration, including the respirable fraction by a factor of at least 2, further contraindicates the Lumsden-Lynch vertical elutriator as an appropriate sampler for the cottonseed oil industry.

Winter

Size-count distributions were similarly accomplished for the dust samples collected during the winter sampling period, so that comparisons could be made between summer and winter occupational environments. Just as obvious as the lower dust concentrations, were the smaller diameter particles collected during the winter sampling. All of the samples collected by vertical elutriation in all of the processes demonstrated 99.9 per cent cumulative distributions (according to size-count) with particles less than 12 μm, and the same observations were true for all samples collected by the MSA personal samplers. The presence of much smaller particles during the winter season was attributed to the processing of "green" seeds and the high relative humidity as compared to the older, drier seeds, and lower relative humidity of the summer. To provide a pictorial comparison with the summer samples, a matched set collected from the cleaning process for the day shift were graphed in the same fashion as were the summer samples from this area (Figures 14-18). The size-count for the Lumsden-Lynch sample is represented in Figure 14 and demonstrates that the largest particle diameter included in the 99.9 per cent cumulative was 11.15 μm. Again, as with the summer samples, a slight convex shaped curve was demonstrated for the particles having diameters less than 4 μm. Figure 15 illustrates the distributions for this same sample according to surface and mass for the particles. If 10 μm is used as the upper limit diameter size of particles posing a health hazard, then 89 per cent would be a problem according to surface area and 66 per cent according to mass. Table 10 provides the median particle sizes and geometric standard deviations for the remaining elutriator samples and again, the high degree of uniformity can be seen.

To provide a comparison with the elutriator sample, Figure 16 depicts the size-count distribution of dust collected

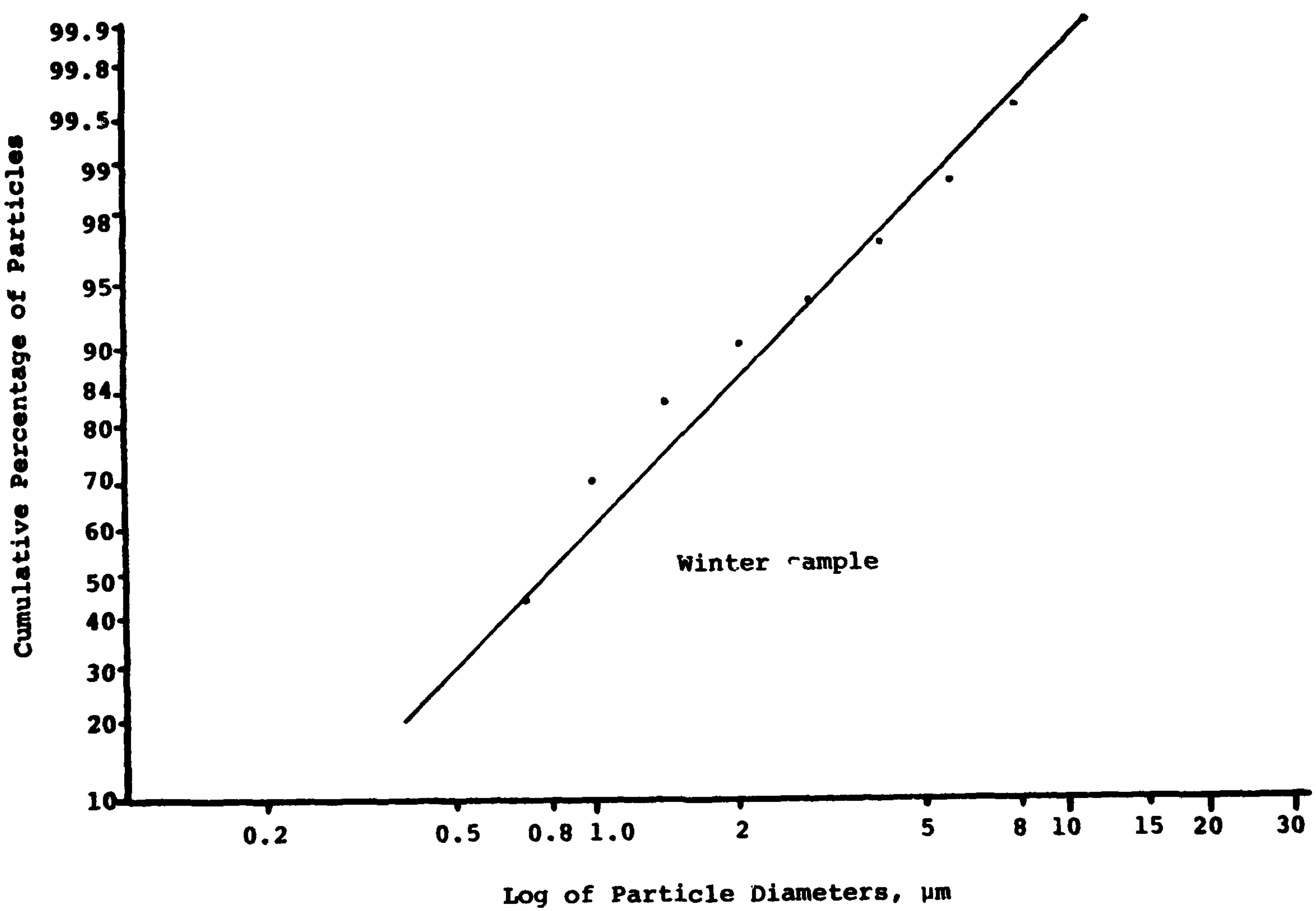

Figure 14. Size-count distribution, cleaning process, day shift, collected by a Lumsden-Lynch vertical elutriator.

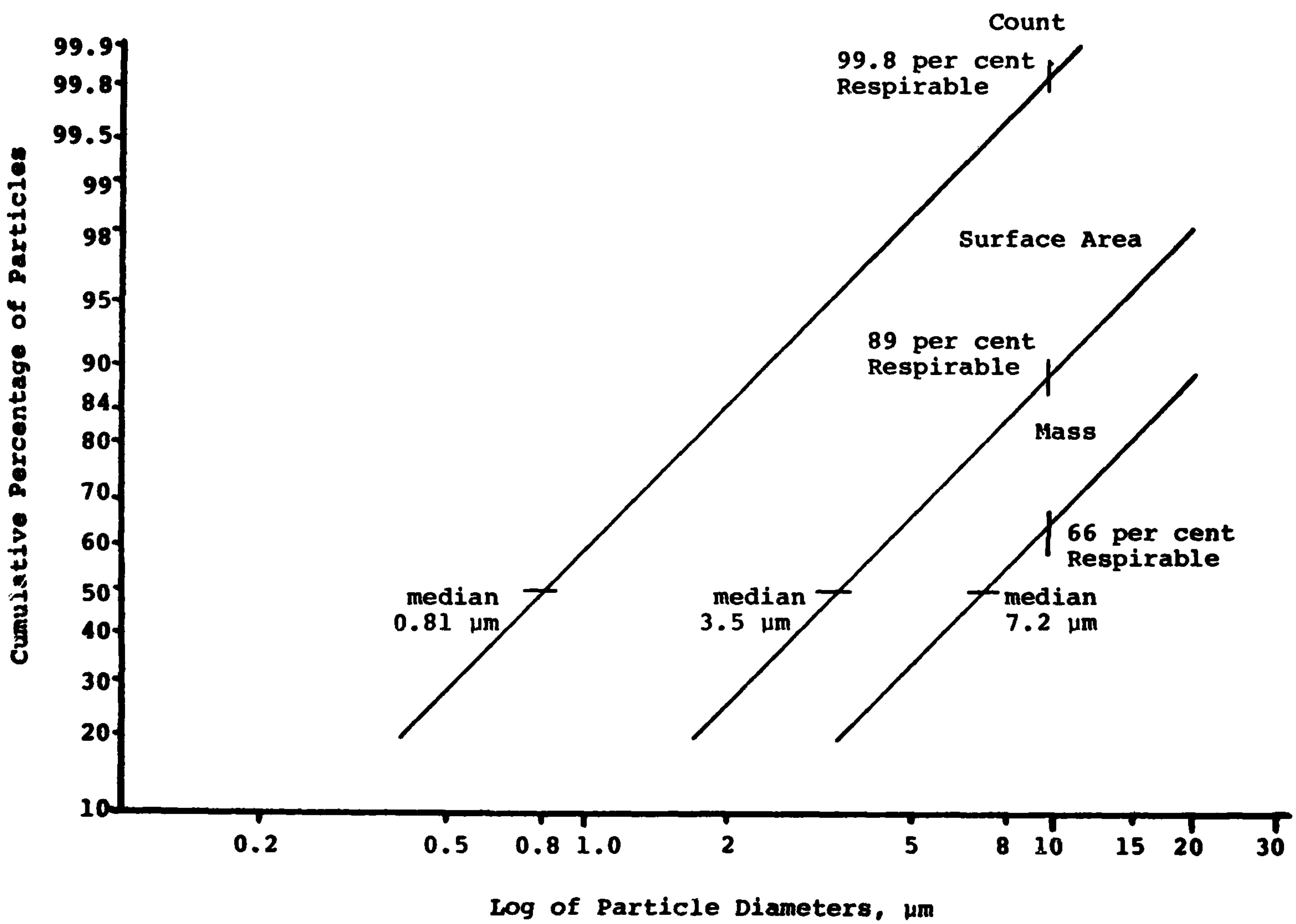

Figure 15. Size-count, surface area, and mass distributions of dust sampled by the Lumsden-Lynch vertical elutriator in the cleaning process during Winter operation.

TABLE 10

MEDIAN PARTICLE SIZE AND GEOMETRIC STANDARD DEVIATION FOR SIZE-COUNTS, SURFACE AREA, AND MASS DISTRIBUTIONS, LUMSDEN-LYNCH VERTICAL ELUTRIATOR, SUMMER SAMPLES

Process		Day Shift			Evening Shift			Night Shift		
		Count	Surface	Mass	Count	Surface	Mass	Count	Surface	Mass
Cleaning	Mp =	0.81	3.48	7.22	0.80	2.37	4.08	0.87	2.93	5.37
	σg =	2.35	2.35	2.35	2.09	2.09	2.09	2.18	2.18	2.18
1st-Cut Delintering	Mp =	0.81	2.89	5.45	0.89	3.31	6.39	0.87	2.93	5.37
	σg =	2.22	2.22	2.22	2.25	2.25	2.25	2.18	2.18	2.18
Hulling and Separating	Mp =	0.83	3.27	6.49	0.83	3.18	6.22	0.86	2.85	5.20
	σg =	2.29	2.29	2.29	2.27	2.27	2.27	2.17	2.17	2.17
Baling	Mp =	0.82	3.38	6.85	0.86	3.39	6.73	0.89	3.51	6.96
	σg =	2.32	2.32	2.32	2.29	2.29	2.29	2.29	2.29	2.29

Mp = Median particle size
σg = Geometric standard deviation

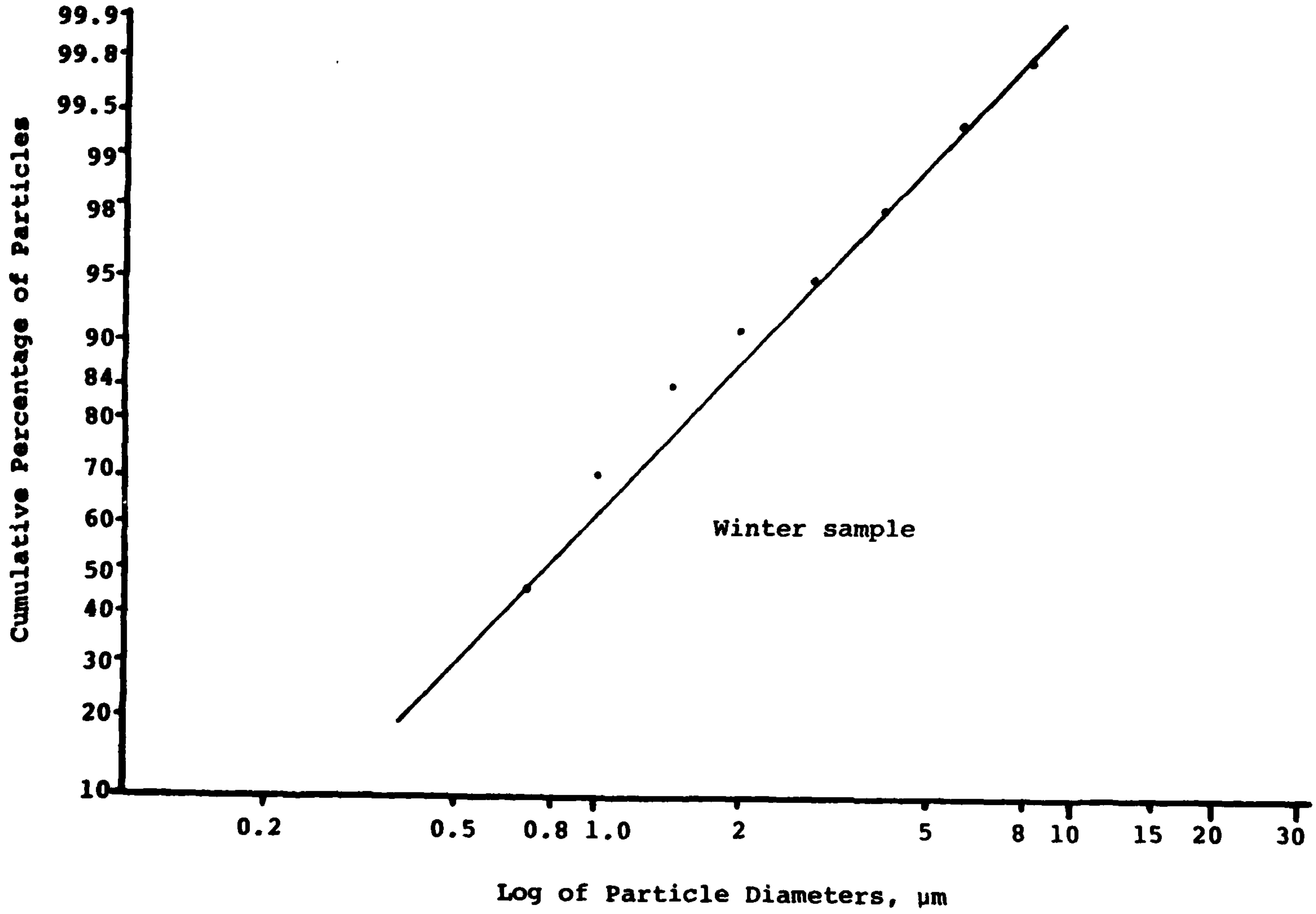

Figure 16. Size-count distribution, cleaning process, day shift, collected by an MSA model S personal sampler.

by a matching MSA personal sampler operated in the cleaning area. The largest particle diameter included in the 99.9 per cent cumulative was 10.76 μm for this sample, confirming the smaller size range for the winter operation. The plotted points again indicated a slight convex shaped curve for the particles less than 4 μm in diameter, further supporting the premise of a heterogeneous sample. Figure 17 provides the surface area and mass distributions which indicate that 89 per cent of the particles were 10 μm or less according to surface area and 72 per cent were 10 μm or less according to mass, thus supporting the previous comments regarding the appropriateness of the vertical elutriator as the specified sampler. Table 11 provides the median particle sizes and geometric standard deviations for the remaining MSA samples.

As for the summer samples, the winter samples were also used to compare the Lumsden-Lynch vertical elutriator and the matching MSA model S personal sampler, by using the largest particle size included in the 99.9 per cent cumulative size-count plots (Table 12). Very obvious is that no particles as large as 15 μm were included by the vertical elutriator but since no particles larger than 15 μm were collected by the MSA sampler, this can be attributed to the absence of large airborne particles rather than the performance of the elutriator.

Table 12 illustrates the decrease in size of the largest 99.9 per cent included particles from the summer operation to the winter operation by having a decrease from

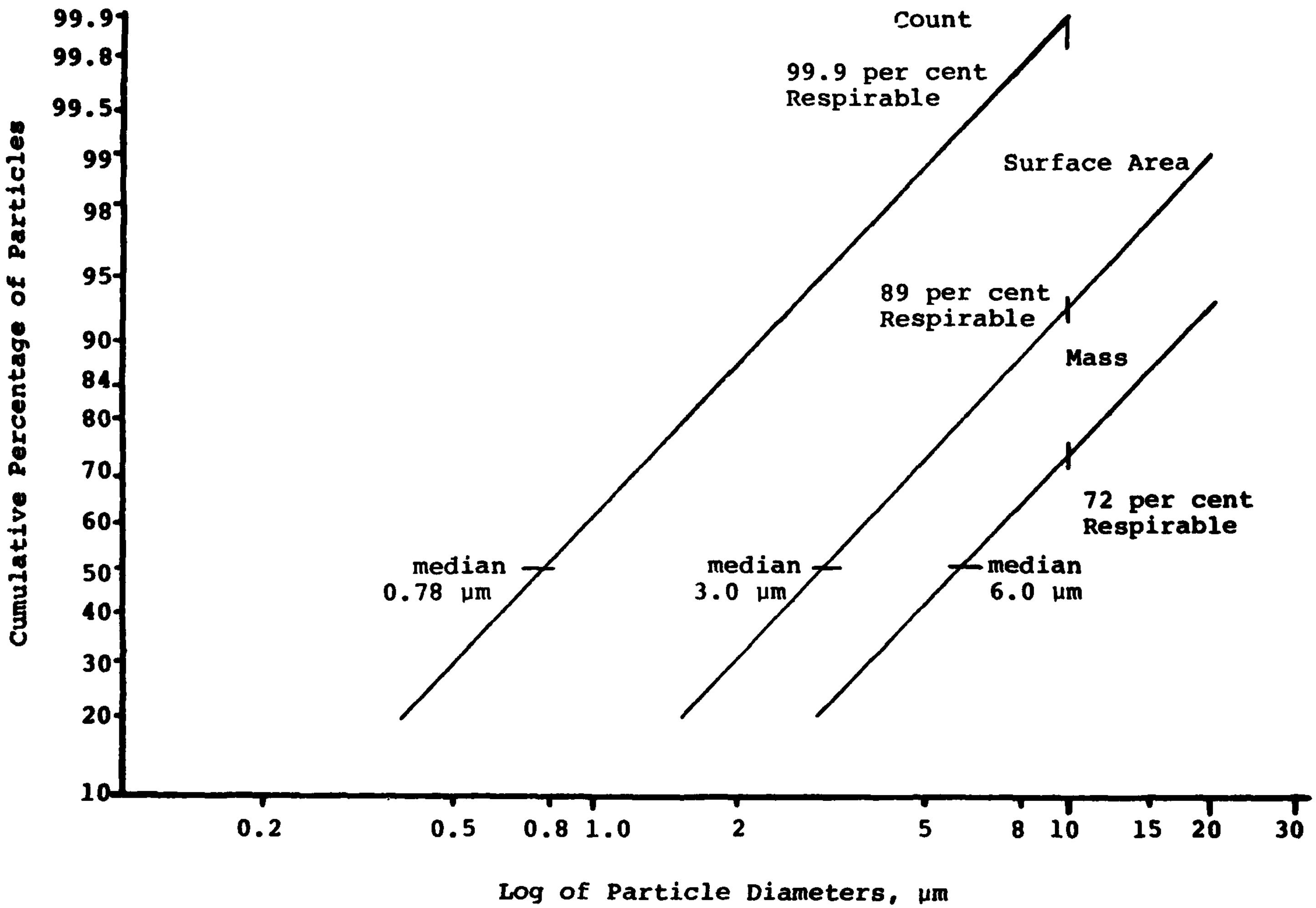

Figure 17. Size-count, surface area, and mass distributions of dust sampled by an MSA model S personal sampler in the cleaning process during Winter operation.

TABLE 11

MEDIAN PARTICLE SIZE AND GEOMETRIC STANDARD DEVIATION FOR SIZE-COUNTS, SURFACE AREA, AND MASS DISTRIBUTIONS, MSA MODEL S PERSONAL SAMPLER, WINTER SAMPLES

Process		Day Shift			Evening Shift			Night Shift		
		Count	Surface	Mass	Count	Surface	Mass	Count	Surface	Mass
Cleaning	Mp =	0.78	3.03	5.97	0.82	2.57	4.55	0.89	3.17	5.99
	σg =	2.28	2.28	2.28	2.13	2.13	2.13	2.22	2.22	2.22
1st-Cut Delintering	Mp =	0.84	2.91	5.41	0.87	2.50	4.25	0.86	2.77	4.98
	σg =	2.20	2.20	2.20	2.07	2.07	2.07	2.15	2.15	2.15
Hulling and Separating	Mp =	0.82	3.09	6.01	0.84	2.67	4.76	0.88	3.18	6.05
	σg =	2.26	2.26	2.26	2.14	2.14	2.14	2.23	2.23	2.23
Baling	Mp =	0.80	3.25	6.54	0.88	3.37	6.59	0.88	3.37	6.59
	σg =	2.31	2.31	2.31	2.27	2.27	2.27	2.27	2.27	2.27

Mp = Median particle size
σg = Geometric standard deviation

TABLE 12

COMPARISON OF THE LUMSDEN-LYNCH VERTICAL ELUTRIATOR AND THE MODEL S MSA PERSONAL SAMPLER, SIMULTANEOUS SAMPLING, WINTER

		Largest Diameter Particles Included in 99.9 per cent Cumulative Particle Counts	
Process	Shift	Lumsden-Lynch µm	Bendix µm
Cleaning	Day	11.15	10.76
	Evening	7.79	9.24
	Night	10.02	11.09
1st-Cut Delintering	Day	10.02	10.53
	Evening	11.18	9.78
	Night	9.24	8.95
Hulling and Separating	Day	10.53	9.99
	Evening	10.94	9.66
	Night	9.77	10.84
Baling	Day	11.94	11.31
	Evening	10.99	11.31
	Night	11.15	11.31
	$\bar{X}$ =	10.39	10.40
	SD =	1.112	0.844

15.4 to 10.39 μm for the vertical elutriator as compared to a decrease from 14.1 to 10.40 μm for the personal sampler. Again, the baling process demonstrated the larger inclusive particles for both types of samplers; however, the other three processes were very similar regarding particle sizes. More fluctuation occurred between samples collected by the same sampler on the same shift than occurred between shifts for the same area, and same sampler.

The data in Table 12 were evaluated for any significant difference between the two types of samplers by using the means of the largest particles included for each sampler by performing an independent sample "t test." At a level of significance of 0.05 and 22 degrees of freedom, there was no difference between the two samplers regarding large particle collection. To further demonstrate the similarities, the size-count distributions for the two samples collected in the cleaning process on the day shift (Figures 14 and 16) were used to prepare an overlay (Figure 18). As this comparison indicates there was virtually no difference in the particle size distributions presented by both samplers, thus indicating the failure of the elutriator to perform selective, size discrimination. This again supports the earlier comments regarding the appropriateness of the Lumsden-Lynch vertical elutriator for this application, and since these devices were constructed according to specifications in the Standard, there is no reason to believe the results are atypical, but characterize the performance of this type of sampler.

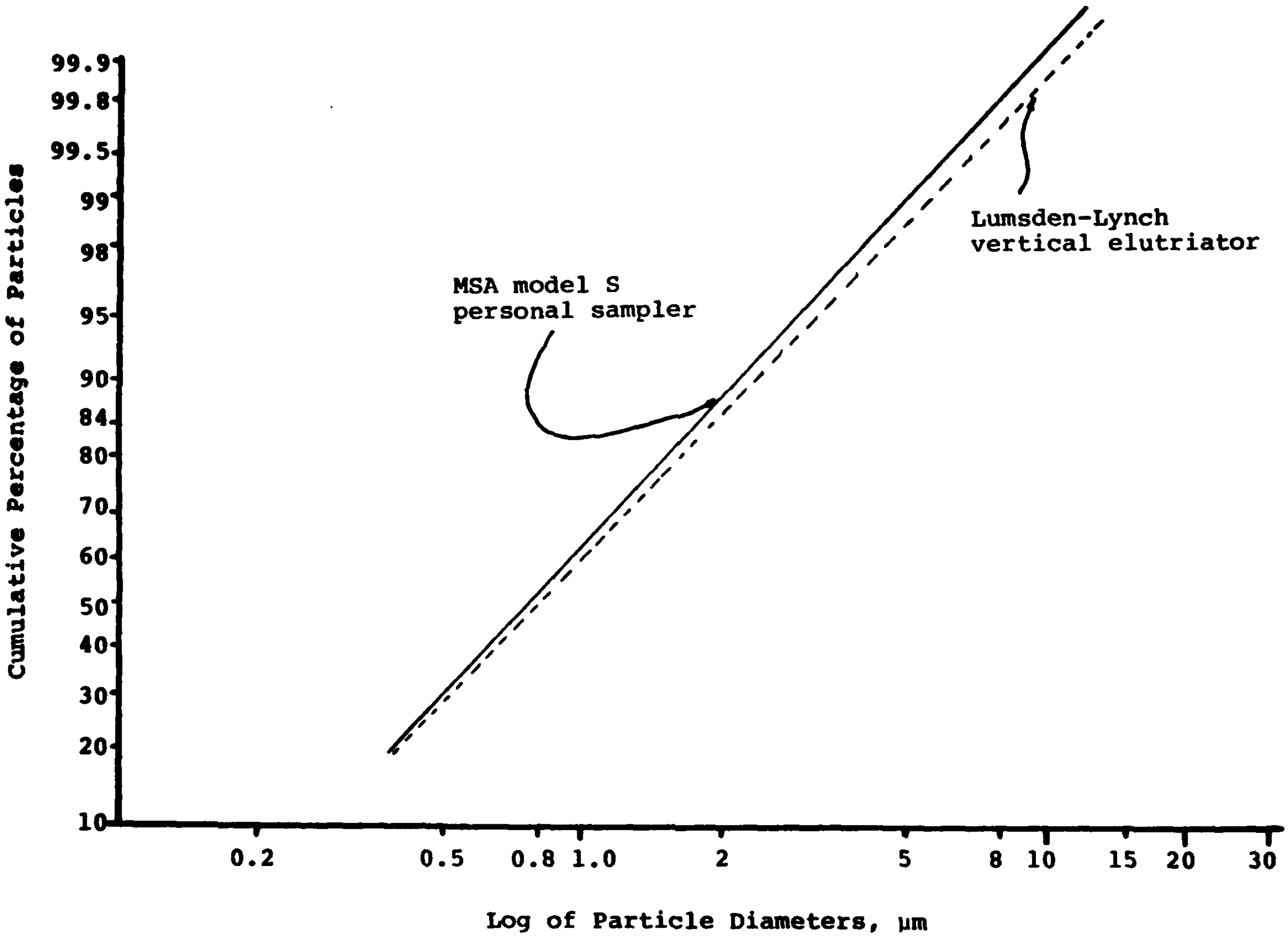

Figure 18. Size-count distributions of dust from the day shift samples collected in the Cleaning process during Winter sampling.

Carbohydrate and Protein Analyses

As described, dust samples were collected with Staplex hi-volume air samplers during summer and winter operations for carbohydrate and protein analyses. The volume of air sampled was so large that dust accumulations, even for very short sampling periods, were difficult to keep intact. Because of this, it was assumed that dust samples collected by these instruments were evenly distributed over the filter surface and losses in handling and transporting would be uniform. With these assumptions, carbohydrate and protein percentages of collected dust weights were estimated from an aliquot analysis for each sample. Percentages for each were estimated by ratioing the aliquot findings with the total dust sample. These results are listed in Table 13 according to process area and season.

TABLE 13

CARBOHYDRATE AND PROTEIN ESTIMATES (PER CENT OF DUST) BY WEIGHT, USING STAPLEX HI-VOLUME AIR SAMPLERS

Season	Area Sampled	Percentage Carbohydrate	Percentage Protein
Summer	Cleaning	6.82	11.54
	1st-cut Delintering	18.86	4.60
	Hulling and Separating	21.94	10.69
	Baling	10.04	-
Winter	Cleaning	35.69	15.09
	1st-cut Delintering	22.09	8.28
	Hulling and Separating	39.13	53.94
	Baling	32.46	9.63

Carbohydrates and proteins are synthesis products of plant and animal life, and one would assume that the major portion of such products observed in the dust of a cottonseed oil mill would be of plant origin; therefore, the data in Table 13 indicate that every process studied did generate dust that contained plant matter. However, the concentrations varied with both process and season, and conceivably the nonplant matter also varied with process and season. Because of the wide variability in the components from process to process and season to season, this technique did not develop into a reasonable approach for quantitatively estimating the nonplant fraction; however, it does support the observations of a heterogeneous material indicated by the particle size distribution. This along with the variability among processes as well as between seasons makes application of a single gravimetric permissible limit highly questionable, especially since the agent(s) active in producing byssinosis remains unknown.

CHAPTER VI

SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

It is obvious from the literature that a serious pulmonary disease (byssinosis) occurs among workers who are occupationally exposed to dusts generated during the processing of raw cotton and certain cotton products. The extent of the disease in the U.S. cotton textile mills was not realized until the studies of Bouhuys et al. (32,33) were reported in the late 1960s. Additional work since that time indicates that as many as 84,000 of the approximately 560,000 cotton industry employees have byssinosis in varying stages and that a minimum of 35,000 have been permanently disabled in just the textile sector of the industry (10). Byssinosis is clinically indistinguishable from emphysema or chronic bronchitis once it progresses to the chronic or irreversible stage. Progression and severity depend on worker susceptibility and the amount of exposure to cotton dust.

In an attempt to alleviate the byssinosis problem, several standards have been proposed and/or imposed on the textile segment and finally in 1978, a permissible exposure limit was established for other components of the industry, including cottonseed oil mills, which presently employ approximately 4,000 workers, who, in 1976, produced $650 million worth of products ranging from oil for human consumption, and meal for livestock to products for use in the paper and chemical cellulose industry (76). For the cottonseed oil mill industry the Standard provides for a permissible exposure limit of 500 $\mu g/m^3$ of lint-free respirable cotton dust averaged over an 8-hour work shift, as collected by a Lumsden-Lynch vertical elutriator which is intended to collect particles that are 15 μm or less in diameter. Though the Standard is specific on dust concentrations by weight and intended particle sizes, it is not so specific on composition and since dust is a heterogeneous mixture it contains varying amounts of components which may differ from process to process, season to season, and industry to industry. The underlying problem is that no component or group of components has been conclusively identified as the etiological agent or agents. An additional concern is that average concentrations of airborne particulate matter have been estimated to range between 58 $\mu g/m^3$ to 180 $\mu g/m^3$ in urban and surburban areas, depending on the size, geographical location, and activity of the city (7). About 60 per cent of these ambient air concentrations is considered to be within the respirable fraction and, therefore, would be collectable by the Lumsden-Lynch vertical elutriator. In states such as Oklahoma, this background represents a significant fraction of the permissible level and could pose serious compliance problems in "open" processes such as the cottonseed oil industry.

Since cottonseed oil mills are one of the very important sub-industries to be included under the 1978 standard, one, which employed approximately 80 workers in a 24-hour per day, 7-day per week schedule and was capable of processing 500 tons of seeds per day was selected for this study.

In evaluating the first objective of this study, which was to identify (using federally specified equipment, procedures, and standards) processes in a cottonseed oil mill that were generating sufficient cotton dust to create an occupational health hazard, Lumsden-Lynch vertical elutriators were utilized to collect samples in the four dust generating areas of the mill. Samples were collected during the three workshifts in cleaning, delintering, hulling and separating, and baling, and were gravimetrically evaluated and compared with the permissible exposure levels in the 1978 standard. During the summer sampling period, when all process areas operated with open windows and doors, and the seeds, which had been stored for almost a year, were at their lowest moisture content, 35 of the 36 samples collected in the four process areas exceeded the 500 $\mu g/m^3$ standard, with one exceeding the standard by a factor of 12. The average concentration of all samples collected in the cleaning process (the dustiest area) exceeded the standard by more than 8.5 times. Dust concentrations did vary during workshifts because of process interruptions; however, only one sample was low enough to be within the standard (493 $\mu g/m^3$, 1st cut delintering, night shift). The fact that the employees in this facility worked more than 8-hours per day and more than 5-days per week makes overexposure of even greater concern.

The same sampling protocol was repeated during December, when green seeds (highest moisture content) and inclement conditions (closed windows and doors) prevailed. Only 39 per cent of the winter elutriator samples were within permissible limits, and most of these were observed on the night shift when work stoppages were occurring more frequently than normal.

Another objective of this study was to compare alternative sampling techniques (gravimetric and microscopic) to evaluate the performance of the Lumsden-Lynch vertical elutriator in a cottonseed oil mill. To accomplish this, personal samplers were used in stationary positions on a side-by-side approach with the elutriators. Summer comparisons were with a Bendix BDX 44 sampler, with concentrations collected by this sampler being approximately double or more their counterpart elutriated sample; however, the real concerns were to determine if the Lumsden-Lynch sampler collected particles larger than the intended upper size limit of 15 μm or not, and if there was any significant difference in the largest particles collected by the two types of samplers. Indeed, the Lumsden-Lynch did collect particles larger than the 15 μm design limit, with 32 of 34 elutriator samples sized and counted during the summer sampling period displaying particles larger than 21 μm in diameter and the other two having particles in the 19- to 21 μm diameter interval. The same was true for the Bendix collected samples, so, the largest inclusive particles in the 99.9 per cent cumulative distributions as determined by the "truncated multiple traverse" procedure for counting and sizing were compared by using the independent "t test" which determined that there was no significant difference between the personal sampler and the vertical elutriator regarding large particle size collection. The sampling protocol was repeated during the winter with an MSA model s personal sampler being used for comparison purposes. Again, the personal samplers collected larger quantities of dust than the elutriators, but there was no significant difference between the two types of samplers pertaining to the largest diameter particles included in the 99.9 per cent cumulative plots. The particle sizes were smaller for both samplers during this period than during the summer, which was not surprising since dust concentrations were much lower and the seeds were very high in moisture content. Overall the vertical elutriator did not seem to discriminate against particles larger than 15 μm any more effectively than the two types of personal samplers used, though 99.9 per cent of the particles collected by the elutriator sampler during the winter operation were less than 15 μm, so were those collected by the personal sampler. In fact, during both sampling seasons the elutriator seemed to provide a false impression that airborne concentrations of respirable dust were much lower than they actually were, when compared with the counterpart personal sampler samples on a gravimetric and microscopic basis.

The objective to develop techniques for estimating the fraction of airborne dust of nonplant origin was approached by determining protein and carbohydrate fractions of dust collected by Stamplex hi-volume samplers in each of the process areas. These analyses indicated component variations with both process and season, and due to the wide variance a reasonable approach for estimating nonplant material was not possible; though, conceivably nonplant material also varied. These data support cotton dust's being a heterogeneous mixture with widely varying components and makes application of a single gravimetric permissible limit very suspect, especially since the agent(s) active in producing byssinosis remains unknown.

The fourth objective was to suggest corrective and/or preventive measures for controlling occupational overexposure to cotton dust if excessive amounts of dust were observed during the study. All work areas evaluated would have been out of compliance with the 1978 cotton dust standard according to concentrations of airborne dust collected by the specified Lumsden-Lynch vertical elutriator (some areas all of the time and others most of the time); therefore, if the permissible exposure limit should be imposed on the industry, then changes would be necessary to prevent worker overexposure. Suggested approaches to prevention are:

a) evaluate the feasibility of enclosing some of the processing equipment in each of the process areas,

b) provide airconditioned cabs for the vehicles used to move seeds and baled linters, and utilize local exhaust ventilation in areas to remove dust at the source,

c) secure appropriate respirators and institute a respiratory protection program in accordance with 29 CFR 1910.134 to provide worker protection in the areas where engineering controls are not feasible,

d) initiate and insure that work practices and procedures are carried out in such a manner that will provide for inspection, cleaning, maintaining, and repairing all engineering control equipment and ventilation systems, including ducts, filtration units, and power sources,

e) formulate appropriate work guidelines and correct any unnecessary routines that lead to increased dust generations and/or undue exposure, such as cleaning by blowing with compressed air when vacuuming can be substituted,

f) isolate the worker from the hazardous environment by either isolating the process and/or providing control booths where the worker may observe the process and enter the hazardous area only to correct problems or perform tasks requiring minimum exposure time,

g) provide preemployment physicals to include a baseline forced vital capacity (FVC), and forced expiratory volume at 1 second (FEV_1) and counseling to those individuals with a positive history of respiratory allergy, chronic obstructive lung disease, or other diseases of the cardio-pulmonary system, or who have a history of smoking, as to the increased risk of being occupationally exposed to cotton dust,

h) after 6 weeks on the job, and following a period of at least 40 hours of no exposure to cotton dust, retest new employees for FVC and FEV_1, at the beginning of the first day back and after 6 hours of exposure on the same day,

i) offer all exposed workers a medical examination on a yearly basis, (more frequent if symptoms indicate) designed to test for FVC and FEV_1 as well as to gain information regarding symptoms of chronic bronchitis, byssinosis and dyspnea,

j) monitor work areas with appropriate sampling equipment at least every 6 months and/or within 30 days of a process change which could adversely affect airborne dust concentrations,

k) evaluating the use of a respirable dust lapel sampler, containing a cyclone vortex, to estimate actual worker exposure, and

l) maintain records on medical evaluations for each employee as well as for area sampling results.

Since the composition of the dust in the cottonseed oil mill was observed to vary with both process and season, the need to identify the etiological agent(s) responsible for byssinosis becomes the most salient observation of this study and indicates the most significant area for future research. Only through this can a single gravimetric standard, hopefully defined in terms of respirable size particles collected by a personal sampler, be logically developed and applied to this industry. As an additional observation, serious consideration should be given to developing and incorporating into the standard a more appropriate sampling instrument than the Lumsden-Lynch vertical elutriator for evaluating respirable dust in the cottonseed oil industry.

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